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NORTH AMERICAN GEOLOGY

FOR

1914

WITH SUBJECT INDEX

BY

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BIBLIOGRAPHY OF NORTH AMERICAN GEOLOGY FOR 1914, WITH SUBJECT INDEX.

By John M. Nickles.

INTRODUCTION.

The bibliography of North American geology, including paleontology, petrology, and mineralogy, for the year 1914 follows the plan and arrangement of its immediate predecessors, the bibliographies for 1906–7, 1908, 1909, 1910, 1911, 1912, and 1913 (Bulletins 372, 409, 444, 495, 524, 545, and 584 of the U. S. Geological Survey). It includes publications bearing on the geology of the Continent of North America and adjoining islands; also Panama and the Hawaiian Islands. Papers by American writers on the geology of other parts of the world are not included. Textbooks and papers general in character by American authors are included; those by foreign authors are excluded unless they appear in American publications.

As heretofore, the papers, with full title and medium of publication and explanatory note when the title is not fully self-explanatory, are listed under the authors, arranged in alphabetic order. The author list is followed by an index to the literature listed. In this index the entries in one alphabet are of three kinds—first, subject, with various subdivisions, to enable the specialist to ascertain readily all the papers bearing on a particular subject or area; second, titles of papers, many of them abbreviated or inverted, under their leading words; and third, cross references, which have been freely used to avoid too much repetition. The subjects have been printed in black-faced type, the titles of papers and cross references in ordinary type. As it may not be always obvious which subject headings have been adopted, a classified scheme of those used immediately precedes the index.

Miss Isabel P. Evans has given efficient assistance in the work.

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CLASSIFIED SCHEME OF SUBJECT HEADINGS.

1. GENERAL.

Associations, meetings; Addresses; History; Philosophy; Biography; Bibliography; Educational; Text-books.

Classification; Nomenclature; Cartography; Technique; Field work; Surveys; Borings.

Geochemistry; Chemical analyses (list); Atmosphere; Radioactivity.

Experimental investigations; Miscellaneous.

2. REGIONAL.

The States of the Union, Alabama, etc.; the Provinces of Canada, Alberta, etc.; Greenland; Mexico; the countries of Central America; the West Indies, and the single islands; the Hawaiian Islands.

3. ECONOMIC.

Ore deposits, origin; Contact phenomena.

Gold; Placers; Black sands; Silver; Quicksilver; Nickel; Cobalt; Copper; Lead; Zinc; Iron; Magnetite; Manganese; Tin; Aluminum; Bauxite; Antimony; Bismuth; Tungsten; Wolframite; Vanadium; Uranium; Carnotite ores; Molybdenum; Molybdenite; Titanium; Rutile; Platinum; Iridium; Rhodlum; Palladium; Cadmium; Monazite; Rare earths; Tantalum; Selenium; Tellurium; Zircon.

Coal; Anthracite; Coke; Peat; Lignite; Bituminous rock; Natural gas; Petroleum; Oil shales; Asphalt; Albertite; Gilsonite; Grahamite; Ozokerite.

Stone; Building stone; Granite; Bluestone; Limestone; Lime; Marble; Onyx; Sandstone; Clay; Kaolin; Bentonite; Fire clay; Ganister; Slate; Shale; Marl; Sand; Glass sand; Sand-lime brick; Gravel; Cement and cement materials; Concrete materials; Road materials; Trap; Steatite; Soapstone; Talc; Serpentine.

Precious stones; Diamonds; Sapphires; Turquoise; Tourmaline.

Abrasive materials; Corundum; Emery; Garnet; Diatomaceous earth; Tripoli; Volcanic ash; Millstones; Novaculite.

Asbestos; Feldspar; Mica; Quartz; Gypsum; Graphite; Fuller's earth; Infusorial earth; Magnesite; Mineral paint; Chromium; Chromite; Chromic iron ore; Fluorspar; Barite; Barytes; Strontium; Arsenic; Pyrite; Sulphur; Sulphate of soda; Cryolite; Phosphorus; Phosphate; Apatite; Potash; Alunite; Glauconite; Borax; Bromine; Salt; Natron deposits.

4. DYNAMIC AND STRUCTURAL.

Earth, genesis of; Earth, age of; Earth, interior of; Earth, temperature of.

Volcanism; Volcanoes; Earthquakes; Seismology; Seismographs; Mud volcanoes.

Isostasy; Orogeny; Changes of level.

Magmas; Intrusions; Dikes; Laccoliths; Metamorphism; Contact phenomena.

Deformation; Folding; Faulting; Unconformities.

Conglomerates; Concretions; Stalactites; Jointing; Cleavage.

Sedimentation; Denudation; Erosion; Caves; Sink holes; Erratic bowlders; Weathering; Wind work; Dunes; Loess; Landslides.

Glaciers; Glacial erosion; Eskers; Kames; Moraines; Kettle holes.

Drainage changes.

5. PHYSIOGRAPHIC.

Geomorphy; Relief maps.

Valleys; Cirques; Deserts; Dunes; Deltas; Alluvial fans; Eskers; Kames; Mounds, natural; Natural bridges; Sink holes; Karsts.

Lakes; Swamps; Marshes; Everglades; Terraces; Beaches; Shore lines; Rivers; Meanders; Falls; Springs.

6. HISTORIC OR STRATIGRAPHIC.

Geologic history; Geologic time; Paleogeography; Paleogeographic maps; Paleoclimatology.

Geologic maps; Geologic formations described (list).

Pre-Cambrian; Paleozoic (undifferentiated); Cambrian; Ordovician; Silurian; Devonian; Carboniferous; Triassic; Jurassic; Cretaceous; Tertiary; Quaternary; Recent; Glacial geology; Glaciation; Glacial lakes; Ice ages.

7. PALEONTOLOGY.

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Vertebrata; Man, fossil; Mammalia; Aves; Reptilia; Amphibia; Pisces; Footprints, fossil.

Invertebrata; Arthropoda; Crustacea; Trilobita; Ostracoda; Insecta; Arachnida; Myriapoda.

Mollusca; Cephalopoda; Gastropoda; Pelecypoda.

Molluscoidea; Brachiopoda; Bryozoa; Vermes.

Echinodermata; Echinoidea; Asteroidea; Crinoidea; Cystoidea.

Cœlenterata; Anthozoa; Hydrozoa; Graptolites.

Protozoa; Spongida; Foraminifera.

Paleobotany; Diatoms.

Problematica.

8. PETROLOGY.

Rocks, origin; Rocks, structural features; Rocks described (list); Igneous and volcanic rocks; Rock-forming minerals; Lava; Oolite; Pebbles.

9. MINERALOGY.

Minerals described (list); Crystallography; Pseudomorphism; Paragenesis of minerals; Rock-forming minerals; Meteorites.

10. UNDERGROUND WATER.

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11. SOILS

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tion. These quadrangles, named in order from southeast to northwest, are the Van Horn, Tex. (Folio 194, by G. B. Richardson); El Paso, Tex. (Folio 166, by G. B. Richardson); Deming, N. Mex. (folio by N. H. Darton in preparation); Silver City, N. Mex. (Folio 199, by Sidney Paige); Clifton, Ariz. (Folio 129, by Waldemar Lindgren); Bisbee, Ariz. (Folio 112, by F. L. Ransome); Globe, Ariz. (Folio 111, by F. L. Ransome); and Bradshaw Mountains, Ariz. (Folio 126, by T. A. Jaggar and Charles Palache). As these quadrangles are distributed along a distance of about 500 miles, much work remains to be done before the differences in stratigraphy and structure between the several areas can be fully explained and the significance of these differences in relation to the general geologic history of the region be clearly understood. Outside of its local resources in underground water and some fluorite deposits of considerable productiveness, Luna County is not known to possess great mineral wealth. Consequently the present report and the Deming folio are likely to prove of most value as contributions to accurate knowledge of a region whose broader geologic problems possess exceptional interest.

GEOLOGY AND UNDERGROUND WATERS OF LUNA COUNTY, NEW MEXICO.

By N. H. Darton.

INTRODUCTION.

This report presents the results of an examination of the greater part of Luna County, in southwestern New Mexico (see fig. 1), made in the autumn of 1910 and some supplemental observations in 1911, 1912, and 1913. The purpose of the work was to determine the geologic structure of the region and to procure all data bearing on prospects for obtaining underground water for domestic use and irrigation. During the last few years many settlers have come into the county and taken homesteads in the broad desert valleys, or bolsons, with the expectation of using underground water for irrigation. They have been encouraged by the excellent results obtained by several of the earlier settlers, and many of them have sunk wells and established pumping plants with satisfactory prospects for successful irrigation. The main source of supply is the widespread underflow fed by the scanty rainfall and also by Mimbres River, a mountain stream which normally passes underground near the northwest corner of the county. This water has been accumulating for a long time and now saturates the gravel and sand deposits underlying most parts of the bolsons. Unfortunately the entire area is not underlain by these water-bearing deposits, and in places the water is too deep or too scanty in amount to be utilized. Therefore one of the principal purposes of the investigation was to determine the extent of the area underlain by water-bearing deposits, the depth to these deposits, and the amount of water available.

The mountains rising out of the bolsons of Luna County exhibit a great variety of sedimentary and igneous rocks, in places containing mineral deposits that have been worked to some extent. Except in some notable bonanza "finds," however, these deposits have not proved very profitable.

TOPOGRAPHY.

MOUNTAINS AND RIDGES.

A large part of Luna County consists of a desert plain, or bolson, mostly from 4,000 to 5,000 feet above sea level and having a general

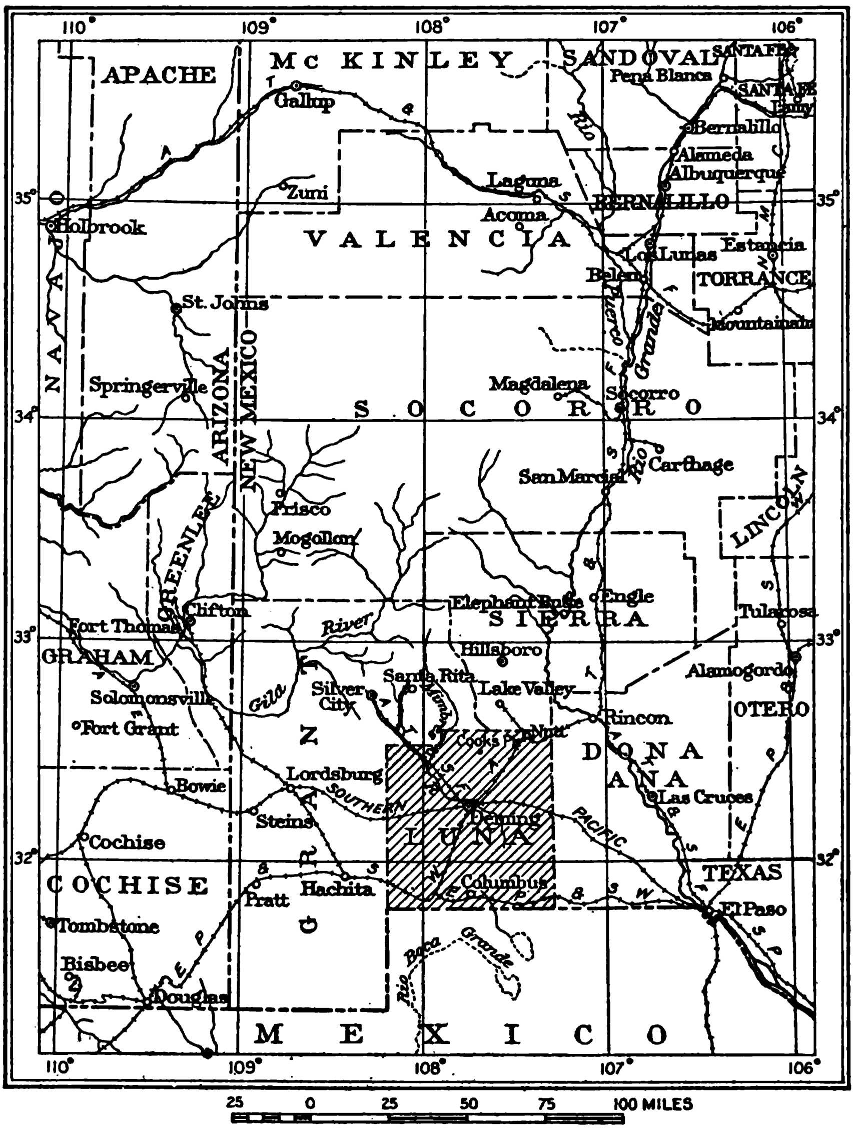

FIGURE 1.—Map of southwestern New Mexico and adjoining region, showing location of Luna County.

up grade to the west. Rising from the bolsons at intervals are narrow rocky ridges ranging in length from 2 to 20 miles and in height

A. VIEW LOOKING SOUTHWEST THROUGH THE PASS ACROSS COOKS RANGE ON OLD BUTTERFIELD ROAD.

The knobs are igneous masses in the agglomerate. The man stands on the grave of party of immigrants massacred by Apaches.

B. COOKS PEAK FROM THE WEST.

Paleozoic limestones in foreground. The peak is porphyry.

A. NORTH END OF FLORIDA MOUNTAINS, 12 MILES SOUTHEAST OF DEMING, N. MEX.

View looking southeast. Most of the rocks are agglomerates and flows. At extreme right edge Paleozoic limestone (L) rests on granite (G).

B. CAPITOL DOME NEAR NORTH END OF FLORIDA MOUNTAINS.

View from the west. The dome consists of agglomerate and igneous flows; below Paleozoic limestones and sandstone lie on granite, which rises in knob at left of view.

A. SOUTH END OF FLORIDA MOUNTAINS.

Shows the wide bolson out of which the mountains rise. This bolson is underlain by water which in places comes nearly to the surface.

B. TRES HERMANAS MOUNTAINS.

Peaks of porphyry 25 miles south of Deming, N. Mex. View looking northwest.

A. THE GREAT SPRING AT OLD FORT CUMMINGS, NORTH OF DEMING, N. MEX.

A natural rock dam across the valley has formed the spring, which is under building near center of view. Remains of fort in distance at the right.

B. GOODSIGHT PEAK, 8 MILES EAST OF FLORIDA STATION, N. MEX.

View looking northeast. Ridge of massive bedded agglomerate on left, overlying sandstone and tuffs. Three sheets of basalt occur in high ridge in distance.

from a few hundred feet to nearly 2,500 feet. The largest of these is Cooks Range (Pl. II) and its outlying ridges, culminating in the conspicuous high summit known as Cooks Peak, which has an altitude of 8,408½ feet. The Florida Mountains (Pls. III, IV, *A*) form a short but very prominent and rugged range a short distance southeast of Deming, rising to an altitude of 7,400 feet, or 2,500 feet above the bolson. They lie in line with Cooks Range, and not far south, on a continuation of the same line, are the Tres Hermanas Mountains (Pl. IV, *B*), which extend nearly to the international boundary. It is probable that all these ridges are portions of one range and have an underground connection not far below the surface in the gaps which separate them. The Cedar Grove Mountains, a long, narrow ridge of considerable prominence, cross the southwest corner of the county; the Carrizalillo Hills are a southern continuation of them and the Klondike Hills an outlying ridge. The Victorio Mountains rise with considerable prominence 3 miles south of Gage, and the Grandmother Mountains are a group of conical peaks 7 miles north of that place. Still farther north are the scattered rocky buttes of the Cow Spring Hills with the conspicuous Cow Cone at their north end. Red Mountain and Black Mountain (Pl. VII, *B*, p. 15) are two small but high buttes rising on the south and north sides, respectively, of Mimbres River, southwest and northwest of Deming. Taylor Mountain and the Fourmile Hills are low dome-shaped areas of rocky ledges a few miles west of Cooks Range. The Goodsight Mountains form a high ridge extending through the northeast corner of the county and culminating in the well-known landmark Goodsight Peak (Pl. V, *B*). The Sierra Rica extends from Mexico into the extreme southwest corner of the county, where it terminates in a group of high limestone buttes. Among minor hills and ridges rising above the bolsons are the Burdick Hills, west of Iola, the Snake Hills, southwest of Deming, some ridges east and northeast of Arena, and some low buttes of basalt west of Mimbres.

The distribution and configuration of these features are shown on the geologic map (Pl. I, in pocket), and further information regarding elevations along certain level lines is given at the end of this report.

BOLSONS.

The smooth desert plain that occupies a large part of Luna County is part of a great plain of gravel and sand which extends continuously across southern New Mexico from the Rio Grande to and over the Continental Divide. Where the Rio Grande has excavated a wide valley 300 feet deep the altitude of this plain is about 4,000 feet, but at the Continental Divide south of Silver City its altitude is about 6,000 feet, showing a general up grade of about 20 feet to the mile. In general in Luna County the plain rises regularly from

less than 4,000 feet on the southeast to 5,400 feet in the northwest corner, an up grade of about 22 feet to the mile, but the slope is considerably greater from Deming northwestward.

From most points of view the plain appears to be flat (see Pl. IV, *A*) with low mounds of sand or shallow arroyos here and there. In places near Deming the Mimbres has cut a trench 15 to 20 feet deep, and some of the local draws have steep banks. There are three prominent rises in the plain—one constituting a step 200 feet high east of Arena and extending northward across the southeast corner of the county; one at the south end of the Tres Hermanas Mountains just east of Mimbres station, a rise of 333 feet; and the third in the Burdick Hills. Toward the mountains the gentle slope of the bolson plain gives place to a much steeper grade, due to a long alluvial fan, a feature which is especially conspicuous around the Florida Mountains.

DRAINAGE.

Mimbres River drains all of Luna County except a small district south of the Cedar Grove Mountains which slopes into Mexico. The Mimbres is usually a running stream at the north margin of the county, but farther south it flows over the surface only when flooded by exceptional rainfall. Its extreme freshet flow rarely extends beyond the central part of T. 25 S. east of the Florida Mountains, but nearly every year the water passes Spalding once or twice, and not infrequently it extends to Deming and beyond. Its flood period is very short, however, and for the greater part of the year most of its bed is dry sand. (See Pl. VI, *A*.)

An important affluent is the San Vicente Arroyo (Pl. VI, *B*), which joins the Mimbres a mile south of Spalding and in time of flow brings a large volume of water from the Silver City district. Cow Creek, draining an area of moderate size in the Cow Spring Hills, is a western branch which seldom flows. The drainage of Cooks Range, the Little Florida Mountains, and the east side and north slope of the Florida Mountains belongs to the main Mimbres system, but it is rare that these waters reach the river channel. A line from Red Mountain to the White Hills and the center of the west side of the Florida Mountains defines a watershed, south of which the surface slopes into the valley of Palomas Arroyo. This arroyo heads in the slopes and ridges in the west-central part of Luna County and in Grant County, and flows through the gap at the north end of the Tres Hermanas Mountains, finally emptying into the Palomas Lakes in Mexico. It occupies a southern continuation of the Mimbres Valley, in the southern part of the country. It flows only at times of freshets, and although these are of short duration sometimes the volume of water is considerable.

A. DRY BED OF MIMBRES RIVER JUST EAST OF SPALDING, N. MEX.

View looking upstream. Cooks Range and Cooks Peak in distance.

B. SAN VICENTE ARROYO NEAR WHITEWATER, N. MEX.

View looking downstream. Shows wide alluvial flat trenched by arroyo working upstream.

A. LIMESTONE KNOBS AT NORTH END OF SIERRA RICA IN SOUTHWESTERN CORNER OF L COUNTY, N. MEX.

View looking northwest. The rocks are of Comanche age.

B. BLACK MOUNTAIN, 8 MILES NORTHWEST OF DEMING, N. MEX.

View from south. Basalt sheet capping Quaternary deposits of gravel, sand, ash, and tuff.

CLIMATE.

The climate of southwestern New Mexico is in general similar to that of districts of similar altitude in a wide district extending from western Texas to the southwestern part of California. The winters are mild, and although the summers are decidedly hot the air is so dry that the heat is much more endurable than the sultry summer weather of the Eastern and Central States. As the altitude of the

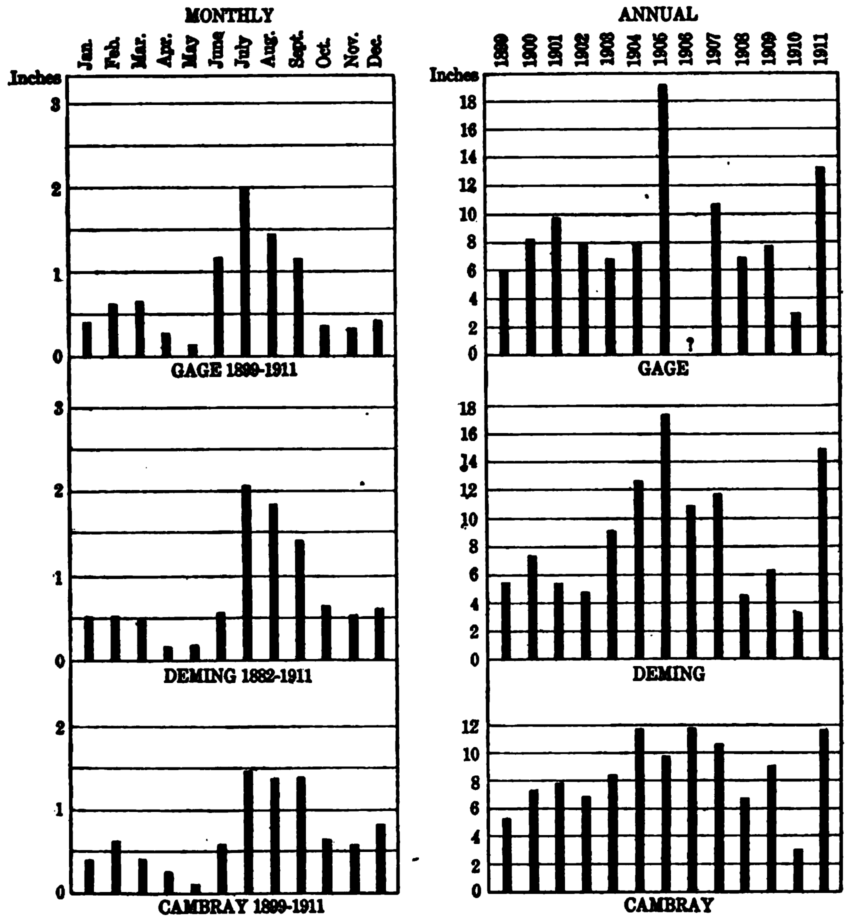

FIGURE 2.—Diagram showing precipitation at Gage, Deming, and Cambray, N. Mex.

greater part of the bolson area ranges from 4,000 to 5,000 feet, the heat is much less than in the lower lands of the Southwest. The principal rainy season is in July, August, and September. The rainfall is moderate, averaging slightly less than 10 inches a year in the lowlands. On the higher ridges the amount is much greater, for many rains and snows fall on the high areas when there is no precipitation in the adjoining desert valleys. The region lies outside of the

normal storm track extending across the central United States, and in consequence the weather is much more uniform than in regions farther north and east. On nearly 300 days in a year there is sunshine for the greater part of the day, and storms of long duration are rare.

The following tables give the monthly and annual precipitation at Gage, Deming, Cambray, and Columbus, and figure 2 shows the annual and average monthly precipitation at the first three points. The data are taken from the reports of the United States Weather Bureau.

Precipitation, in inches, at Deming, N. Mex., 1882–1911.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1882	0.75	1.00	0.50	0.00	0.00	0.43	1.22	2.55	0.52	0.00	1.54	0.20	8.71
1883	.10	.00	1.77	.00	.00	.10	2.95	1.41	.53	1.32	.30	.88	9.36
1884	.80	.70	.20	.20	.00	.00	.52	1.04	.80	1.53	.54	1.35	7.68
1885	.00	.75	.52	.00	.77	1.33	1.38	.81	.09	.28	.50	.91	7.34
1886	.68	.50	.00	.00	.00	.00	1.13	4.19	4.36	.50	.00	.00	11.36
1887	.00	.20	.00	.00	.00	.00	2.02	3.46	3.39	2.13	.31	.05	11.56
1888	.26	1.77	.24	.50	.70	.50	1.08	.60	.00	1.60	1.45	.27	8.97
1889	1.09	.10	.12	.05	.00	.90	1.09	.64	3.55	.84	.80	.00	9.18
1890	.53	.00	.00	.13	.00	.16	4.09	2.20	2.26	.47	.42	1.25	11.51
1891	.40	.53	.64	.00	.48	.14	.18	1.20	.80	.00	.00	.18	4.55
1892	.45	.86	1.34	.10	.00	.90	.20	.39	.08	1.21	1.80	.60	7.93
1893	.19	.59	.42	.00	1.45	.01	2.82	4.38	2.64	.00	.06	.10	12.66
1894	.05	.66	.45	.00	.00	.00	.65	.95	Tr.	.45	.00	.36	3.57
1895	.50	.15	.00	Tr.	.58	.25	3.76	.35	.00	.15	.90	.15	6.79
1896	.60	Tr.	.00	.20	.00	.15	4.30	1.95	2.00	3.25	.25	.00	12.70
1897	1.55	.20	.42	.00	.00	.50	2.89	1.41	1.87	1.57	.00	Tr.	10.41
1898	.75	Tr.	1.42	.30	.00	Tr.	1.66	1.73	.21	.00	.10	.60	6.77
1899	.05	Tr.	.00	.00	.00	Tr.	3.92	.78	.54	Tr.	.45	Tr.	5.74
1900	.56	.46	.74	.00	.10	Tr.	2.40	.08	3.10	.20	.04	.03	7.41
1901	.40	1.87	.11	Tr.	Tr.	Tr.	.98	.90	.05	.75	.31	Tr.	5.37
1902	Tr.	Tr.	Tr.	.00	.20	.00	.91	1.61	.36	.01	.27	1.30	4.66
1903	.49	.85	1.00	.00	.13	3.32	.01	.40	2.84	.00	.00	.05	9.09
1904	.00	.00	.00	.00	.00	.60	1.57	1.58	4,16	.80	.64	1.18	12.53
1905	1.53	2.08	2.15	1.87	.00	1.05	.90	1.25	2.74	.32	2.72	.98	17.59
1906	.66	.63	.56	.10	.05	.00	1.98	2.98	.64	.02	1.34	1.83	10.79
1907	1.42	.08	.06	.19	.39	.35	3.18	1.95	2.40	.41	1.26	.00	11.69
1908	.64	.31	.18	.94	.03	.08	1.18	1.01	.00	.00	Tr.	.13	4.50
1909	Tr.	1.03	.51	.00	.00	.02	.40	1.58	.88	.89	.00	.70	6.01
1910	.00	.00	.19	.02	.00	.43	.96	1.02	.80	.00	.00	.00	3.42
1911	.77	1.40	.67	.38	.00	.96	7.13	.30	1.77	1.30	.00	.42	15.10
Mean	.53	.53	.49	.18	.18	.59	2.07	1.86	1.43	.69	.52	.63	9.70

1908, first killing frost Oct. 19; last, Mar. 19; 23 rainy days; 231 clear; 91 part cloudy; 44 cloudy; 1 foot snow.

1909, first killing frost Oct. 19; last, Apr. 23; 23 rainy days; 230 clear; 107 part cloudy; 28 cloudy; 10½ inches snow.

1910, first killing frost Oct. 20; last, Mar. 30; 14 rainy days; 136 clear; 136 part cloudy; 96 cloudy; no snow.

1911, first killing frost Oct. 22; last, Mar. 13; 40 rainy days; 167 clear; 102 part cloudy; 96 cloudy; 5 inches snow.

Precipitation, in inches, at Gage, N. Mex., 1899–1911.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	0.36	0.20	0.16	0.12	Tr.	0.00	3.40	1.00	0.15	0.10	0.10	0.11	5.70
1900	.16	.35	.83	.15	.00	.27	1.65	.75	3.13	.28	.63	.00	8.20
1901	.28	.99	.11	.00	.00	.45	3.05	2.08	.30	1.45	1.00	.00	9.71
1902	.00	.30	.00	.00	.00	.24	1.45	3.02	1.10	.10	.52	1.30	8.03
1903	.27	.20	.90	.00	.25	1.20	.51	.72	2.84	.00	.00	Tr.	6.89
1904	Tr.	.00	.00	.00	Tr.	.62	1.16	1.35	.65	2.00	.55	1.50	7.83
1905	1.60	3.00	2.95	1.78	.06	.62	1.17	2.25	2.04	.44	2.80	.75	19.46
1906	......	......	......	......	......	......	......	.41	.84	.00	.47	2.40	......
1907	1.41	.11	.15	.13	.62	.98	1.67	2.05	1.31	1.18	1.10	.00	10.71
1908	.56	.22	.17	.74	.12	.00	1.92	2.15	.31	.00	.10	.70	6.99
1909	.04	.15	1.40	.00	.00	2.32	.00	1.97	.45	.00	.00	.45	7.68
1910	.23	.00	.20	.04	.14	.50	.68	1.00	.05	.00	Tr.	.00	2.84
1911	1.06	1.00	.50	.20	.00	1.30	4.50	.30	2.20	1.00	.00	.72	13.38
Mean	.36	.63	.66	.28	.12	.66	1.96	1.47	1.18	.38	.35	.47	8.52

Precipitation, in inches, at Cambray, N. Mex., 1899–1911.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	0.05	Tr.	0.10	0.27	0.00	0.31	1.90	0.64	0.98	0.00	0.54	0.18	4.97
1900	.00	.70	.90	.00	.45	.17	1.67	.62	1.78	.10	.45	.10	6.94
1901	.31	.59	.08	.10	.05	.35	2.02	.19	.37	2.95	.70	.00	7.71
1902	.00	.04	.05	.00	.24	.32	.67	1.72	1.53	.02	.60	1.45	6.64
1903	.74	1.55	.80	Tr.	.40	.43	.09	2.58	1.43	.00	.00	.00	8.02
1904	.04	.10	.00	.02	.12	.18	.82	1.19	5.23	1.48	.50	1.78	11.46
1905	1.69	2.01	1.02	.55	.00	.50	.75	.50	.50	Tr.	1.50	.60	9.62
1906	.65	.72	.60	1.20	.00	.00	1.65	2.57	1.39	.00	1.38	1.28	11.44
1907	.65	.00	.00	.00	.23	1.15	1.72	.60	2.05	3.01	1.10	.00	10.51
1908	.27	.28	.00	.53	.00	.00	1.64	3.15	.00	Tr.	.45	.10	6.42
1909	Tr.	.10	1.00	.00	.00	2.05	1.40	2.60	1.25	.00	Tr.	.60	9.00
1910	.20	.00	.08	.40	.00	.95	.79	.91	.03	Tr.	.02	.00	3.38
1911	.80	1.87	.55	.33	.00	1.25	3.80	.40	1.31	.31	Tr.	.66	11.28
Mean	.36	.61	.40	.26	.11	.59	1.46	1.34	1.37	.61	.56	.80	8.19

Precipitation, in inches, at Columbus, N. Mex., 1910–11.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
1910	0.14	0.03	1.13	0.09	0.01	2.34	0.54	1.17	0.35	0.03	0.19	Tr.	6.61
1911	.65	1.03	.05	.23	.00	.81	5.19	.09	1.81	.50	.21	.97	11.54

1910, first killing frost Oct. 21; last, Mar. 30; rainy days, 29; clear days 227; partly cloudy, 42; cloudy, 96.
1911, first killing frost Oct. 22; rainy days 34; clear days 203; partly cloudy, 70; cloudy, 92.

The mean monthly and annual temperatures of Luna County are much more uniform than the rainfall. The hottest month is June in some years and July or August in other years. December is usually the coldest month. The following tables are taken from the records of the United States Weather Bureau:

Monthly and annual temperatures, in degrees Fahrenheit, at Deming, N. Mex., 1908–1911.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1908	41.8	43.6	52.6	56.4	64.4	76.6	72.2	72.6	70.3	56.2	46.7	41.9	57.9
1909	45.8	43.0	48.2	58.6	64.0	78.6	81.2	74.4	70.2	62.5	52.0	37.0	59.6
1910	43.0	44.8	57.2	58.9	70.3	78.0	80.6	78.5	76.2	62.3	51.7	42.8	62.0
1911	43.3	43.2	54.9	57.2	65.8	76.1	76.7	78.6	72.7	62.6	45.2	33.4	59.1
Mean	......	......	......	......	......	......	......	......	......	......	......	......	59.6

Monthly and annual temperatures, in degrees Fahrenheit, at Gage, N. Mex., 1908–1911.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1908	42.4	44.7	53.8	56.8	63.8	74.2	77.9	76.3	70.6	54.9	46.4	40.5	58.5
1909	47.4	44.4	50.0	58.7	68.8	78.6	79.6	75.7	70.0	65.1	51.4	37.0	61.8
1910	43.3	46.8	56.8	59.8	69.6	78.2	81.1	78.8	72.4	66.7	51.6	43.4	62.4
1911	46.0	45.0	56.0	57.8	67.4	75.9	75.2	79.4	75.5	60.2	44.2	35.0	59.8
Mean	......	......	......	......	......	......	......	......	......	......	......	......	60.6

GEOLOGY.

GENERAL RELATIONS.

In southwestern New Mexico there is a thick succession of sedimentary rocks ranging from Cambrian to Recent in age and lying on pre-Cambrian granite, which appears in some of the hills and mountains. There are also many kinds of later igneous rocks—porphyries, latites, andesites, rhyolites, and basalts—some of them surface flows and others intruded among the sedimentary rocks. The wide smooth-surfaced valleys known as bolsons are filled with sand, clay, and gravel, in places overflowed by sheets of relatively young basaltic lava. The older sedimentary rocks are in widespread sheets, but they are considerably flexed and faulted and appear in scattered ridges rising out of the bolsons. They comprise a basal sandstone of Cambrian age, two limestones of the Ordovician, a thin representative of the Silurian, black shale of the Devonian, two great limestones representing the Mississippian and Pennsylvanian epochs of the Carboniferous period, a formation of shale and limestone of unknown equivalence, but tentatively regarded as of possible Triassic age, representatives of the early and later Cretaceous, and thick bodies of sands, clays, and gravels of Quaternary age. Tertiary time appears to have produced a great succession of igneous rocks, partly in thick accumulations of agglomerate, tuff, and ash and thin sheets of various kinds of lavas. Much of this material underlies the bolsons. Some portions of geologic time are not represented by known deposits in the region, notably the earlier Cambrian, Jurassic, and possibly the Triassic, also portions of the Ordovician, Silurian, Devonian, Carboniferous, and Cretaceous. The Mississippian and Devonian, which are prominent in the northern part of Luna County and adjoining regions, are absent to the south, but this is the only important notable local variation in the succession. The general distribution of the formations is shown on Plate I (in pocket), and their names, general character, thickness, and classification are given in the following table:

Sedimentary formations in Luna County, N. Mex.

System.	Series.	Formation.	Thickness (feet).	Character.
Quaternary.		Bolson deposits.	1,665±	Sand, clay, and gravel.
		—Unconformity—		
Tertiary.		Agglomerate.	2,000+	Fragmental volcanic materials, in part water-laid, and sand and gravel. Igneous sheets at intervals.
		—Unconformity—		
Cretaceous.	Upper Cretaceous.	Colorado shale.	300+	Gray shale with impure thin limestone and sandstone layers.
		—Unconformity—		
	Comanche (Lower Cretaceous).	Sarten sandstone.	300	Massive gray sandstone, in part quartzitic.
		Limestone of Comanche age.	0–400	Gray limestones, mostly slabby, and sandy shale.
		—Unconformity—		
Triassic (?).		Lobo formation.	95–500	Reddish shale, impure limestone, and conglomerate.
		—Unconformity—		
Carboniferous.	Pennsylvanian.	Gym limestone.	30–1,000	Gray limestones, some dark, in part brecciated; dark shale member.
		—Unconformity—		
		Magdalena formation.	0–40	Shale and slabby limestone.
		—Unconformity—		
	Mississippian.	Lake Valley limestone.	0–700	Light-gray limestone with shale members; chert at top.
Devonian.	Upper Devonian.	Percha shale.	175	Black shale.
Silurian.		Fusselman limestone.	100–300	Massive gray limestone.
Ordovician.	Upper Ordovician.	Montoya limestone.	300	Gray limestones with thick chert members; dark limestone at base.
		—Unconformity—		
	Lower Ordovician.	El Paso limestone.	500–800	Light-gray limestones, mostly slabby.
		—Unconformity (?)—		
Cambrian.	Upper Cambrian.	Bliss sandstone.	30–200	Sandstone and sandy shale; glauconitic.
		—Unconformity—		
Pre-Cambrian.		Granite.		

THE ROCKS.

PRE-CAMBRIAN ROCKS.

GENERAL CHARACTER.

The general basement of Luna County consists of pre-Cambrian crystalline rocks, which appear at the surface in several areas of small extent. They are overlain unconformably by the sedimentary rocks, the contact showing an irregularly eroded surface of granite, which is the prevailing rock in the outcrop areas. Its age is not

known, except that it is pre-Cambrian. Some portions of the granite are gneissic, and in places it includes syenitic and porphyritic masses and hornblende dikes of unknown age.

DISTRIBUTION.

The most extensive exposures of granite are in the Florida Mountains, which consist largely of that rock. It appears also in the north end of Cooks Range, in small areas on the slopes south and north of Fluorite Ridge, and as a very small outcrop in the midst of the Klondike Hills. The area in the Florida Mountains is nearly 30 square miles in extent, and here the rock constitutes peaks and ridges reaching an altitude of 7,000 feet, or 2,500 feet above the adjoining bolson. This large granite area is terminated on the north by a fault, but the rock reappears just west of Capitol Dome and extends northward along the foot of the range for a mile to another fault which carries it far below the surface.

RELATIONS AND AGE.

The granite is Algonkian or Archean in age, but as its relations to the older rocks are not exposed there are no means of determining in which system it belongs. It is all of igneous origin and part of one great mass except, possibly, a small amount of rock of gneissic and dioritic character which may be projections or inclusions of an older complex. It is overlain unconformably by the Bliss sandstone, of Upper Cambrian age, and the contact shows the usual features of shore deposition without sign of metamorphism in the sandstone or change of texture in the granite. At several places the granite adjoins higher sedimentary rocks, but these contacts are faults. On the slope 2 miles south of Gym Peak the granite is so intricately faulted that it appears to include and to penetrate the upper beds of the Gym limestone, but the limestone is not metamorphosed and the granite retains its coarse grain up to the contact and shows evidence of crushing; the relations indicate a complex overthrust. In the Pony Hills the granite is brought into contact with the Sarten sandstone, probably by faulting, but possibly by overlap.

A dike of amphibolite outcrops in the slopes a short distance south of Capitol Dome and diorite appears at several places along the west slope of the Florida Mountains. Both of these rocks appear to be of pre-Cambrian age. Some small masses of rock of porphyritic character in the granite areas may be younger intrusives. In the eastern part of the pre-Cambrian area west of Fluorite Camp there is a mass of diorite which is penetrated by light-colored granite and finally gives place to that rock in the slopes farther west. Well-developed gneiss occurs in large angular fragments in a coarse breccia which

lies in the south slopes of this same ridge half a mile northwest of Fluorite Camp. This breccia lies on the limestones and porphyry and appears to have been brought up by a local explosion or by the porphyry intrusion. The principal rock in the small outcrop in the Klondike Hills is typical gneiss, and part of the rock in the basin north of Fluorite Ridge is distinctly banded.

PETROGRAPHY.

By John L. Rich.

Most of the granite is a massive, coarse-grained, pale reddish to light greenish-gray rock weathering into rugged forms of brownish aspect. Local variations in color and texture are subordinate features. It has a uniform mineral constitution, consisting essentially of feldspar, quartz, chlorite, and iron oxides, but in general the granite of the Florida Mountains contains a larger proportion of soda feldspars than that farther north. The predominating granite in the Florida Mountains near Capitol Dome (Pl. III, *B*, p. 13) and to the south is light pink and of medium to coarse texture. It consists almost entirely of microperthite and quartz, the former slightly in excess. The quartz crystals show strain and are somewhat shattered. The original existence of a small amount of mica is indicated by characteristic outlines now filled with iron-stained chloritic aggregates. Accessory minerals are magnetite, apatite, and zircon.

The granite of the Florida Mountains presents, in areas of small extent, some local variations from the type described above. South of Capitol Dome, for instance, a gray, rather fine grained, slightly porphyritic granite differs from the type principally in having a markedly finer texture and apparently a greater proportion of quartz. A pinkish granite occurring south of The Park differs from the type only in having a higher proportion of quartz. The red color of this rock, as well as of most of the granite of the Florida Mountains, is due in part to staining by hematite, which, as a product of the decomposition of the femic minerals, has spread into the cleavage cracks of the feldspar and into the fracture planes of the quartz crystals.

In external appearance the granite from the north end of Cooks Range closely resembles the massive pinkish rock just described as typical of the Florida Mountain localities. It differs, however, in having the albite in the form of separate crystals rather than as microperthite. It has an even granular texture of medium coarseness with crystals averaging 2 to 5 millimeters in diameter. It is composed essentially of quartz, microcline, a subordinate amount of albite, scattered crystals of andesine, and a greenish-brown biotite. The quartz in some crystals shows incipient granulation. In the granite of Fluorite Ridge the albite and orthoclase are in separate

crystals, but otherwise the rock is closely similar to that of the Florida Mountains. The granite of the Pony Hills, north and northwest of Fluorite Ridge, is mostly light pinkish to gray and has a moderately coarse texture.

The granite of the Klondike Hills differs slightly from the others. Two varieties, both having well-developed gneissic banding, are distinguished. The first is a biotite granite of strong red color and coarse texture; the second is distinctly porphyritic, having white phenocrysts of albite oligoclase lying in a dark medium-grained matrix of quartz, albite, and green biotite. It contains considerable epidote.

Portions of the granite on the slope south of Capitol Dome are gneissic. At one place a fine-grained light-gray granitic or aplitic gneiss, composed almost entirely of quartz and feldspar (orthoclase and albite), with very subordinate ferromagnesian minerals, has distinct gneissic banding revealed by the stringing out of the few dark constituents. A typically granitic rock with pronounced gneissic banding is found in large fragments in the breccia on the limestone and porphyry on the south slope of Fluorite Ridge. Its color is gray with a pink to purplish tinge; its texture medium, with feldspars reaching a maximum length of 3 millimeters. A somewhat similar gneissic granite of dull-gray color and slightly finer grain occurs in places in the Pony Hills, north of Fluorite Ridge. A third notable variety crops out on the lower slopes of the ridge half a mile southwest of Fluorite Camp, about 500 yards south of the breccia just mentioned. It is bright red and of medium, even granular texture, with banding only slightly developed, though the microscope reveals strong granulation of the quartz. As noted on a preceding page, part of the granite of the Klondike Hills is gneissic.

Although the gneissic granites just described differ somewhat in color, texture, and the extent of banding and granulation, they are closely similar in composition and doubtless of the same age.

Part of the granite at the foot of Fluorite Ridge, southwest of Fluor mine, has a marked green color and is notably porphyritic. Phenocrysts of pink orthoclase as much as 2 centimeters in length by 1 centimeter in width are embedded in a granular matrix of albite, biotite, and quartz. Granulation of the quartz and a stringing out of the mica flakes indicate that the rock has been subjected to slight dynamic disturbance.

The granitic mass of the Florida Mountains include some light-gray rocks differing considerably from the normal pink granite. These outcrop in the slopes west of Arco del Diablo and also in the pass east of The Park, in the central portion of the Florida Mountains. They are either local developments, intrusions into the ordi-

nary pinkish granite, or, possibly, irregular dikes of post-Cambrian age. They are moderately coarse grained, the crystals averaging about 1 centimeter in diameter. Fresh specimens have a slaty blue to drab color and weather yellowish brown. They are composed almost entirely of feldspar and quartz, the quartz always in small amounts but varying considerably in specimens from different localities. The feldspars are sodic, anorthoclase and albite predominating. At the Window Mountain mine, southwest of Arco del Diablo, is a finer-grained phase which has a higher quartz content and a considerable proportion of potash feldspar. A closely similar rock is associated with the gneissic granite just south of Capitol Dome.

The more siliceous types of the rocks cutting or included in the granite of the Florida Mountains approach sodic granite porphyries in character, while some of the more basic rocks are related closely to the typical quartz monzonite porphyries. All are moderately dark, with a greenish-gray cast. White phenocrysts of feldspar as much as 15 millimeters in length, mostly albite, lie embedded in a darker fine-grained groundmass of orthoclase, albite, and oligoclase in varying amounts, green hornblende, in part at least derived from augite, and biotite. In addition to the usual accessory minerals there is a little pyrite.

Dark, heavy rocks of two or three kinds are found in the granite at several places in the Florida Mountains and about Fluorite Ridge. The most numerous are dikes of amphibolite which traverse the granite south and west of Capitol Dome. These rocks are moderately fine grained and are composed essentially of green hornblende, together with a small amount of albite and a little quartz.

On the lower slopes half a mile southwest of Fluorite Camp a rock of similar character is associated with the granite and probably cut by it. The rock is almost black, with lighter bands of feldspar. The texture varies in different bands, the crystals of some reaching a diameter of 1 centimeter. Green hornblende predominates, and the feldspar ranges from oligoclase to andesine. More or less gneissic banding is developed in most of these rocks.

In the granite at Capitol Dome is a dike or included mass of porphyritic diorite with phenocrysts of white labradorite as much as 8 millimeters in diameter set in a dense dark-green to black fine-textured groundmass of diabasic character.

CAMBRIAN SYSTEM.

BLISS SANDSTONE.

DISTRIBUTION AND RELATIONS.

At the base of the Paleozoic succession in Luna County there is a sandstone that stratigraphically and lithologically so closely resembles the Upper Cambrian Bliss sandstone, of the El Paso region,

that the name Bliss is here applied to it. Its thickness ranges from 150 to 200 feet in most of the area, but in places it is considerably less. In the Florida Mountains the formation crops in the lower slopes west of Capitol Dome, in the cliffs east of The Park, and in the long slope just north of Gym Peak. In the slope west of Capitol Dome the sandstone is exposed for a mile, lying on granite. It disappears under the bolson at the south and is cut off by a fault to the north. The exposures east of The Park are less than a mile in length, and their continuity is interrupted by faulting and talus. In some of the outcrops northwest of Gym Peak the sandstone appears to be absent locally, but possibly in places this apparent absence is due to faulting. In the long outcrop down to the slope and spurs north of Gym Peak the sandstone is well exposed, extending northward to the draw, where it is finally cut out by a fault. In Fluorite Ridge the nearly vertical beds of sandstone lie against the granite but apparently are separated by a fault of small throw a short distance west of Fluorite Camp. In the north end of Cooks Range the Bliss sandstone rises gradually out of the bolson on the west side, caps the ridge for a short distance, and is cut off by the fault on the east side. In the Klondike Hills there is a small exposure of the sandstone separating granite from the El Paso limestone, but apparently it is cut off by a slight fault on the west side of the granite area. It is thin at this locality and may possibly thin out at one or two places.

The Bliss sandstone consists mainly of gray to brown sandstone, in part quartzitic, in members 30 to 40 feet thick separated by sandy shale. In Cooks Range and Fluorite Ridge and near Capitol Dome the upper beds are slabby sandstone and sandy shale with intercalated thin limy beds. Some of the sandy shale contains a large amount of green glauconite in disseminated grains, a feature characteristic of some of the Cambrian rocks in other regions. The basal contact is well exposed in the area west of Capitol Dome, in the Florida Mountains, where coarse sandstone lies on the slightly uneven eroded surface of the coarse-grained pinkish granite. The basal beds are arkosic and pebbly, and their material is evidently derived from the granite. Similar conditions are exposed east of The Park and north of Gym Peak. At its top the sandstone gives place abruptly to the El Paso limestone without discernible evidence of erosional unconformity to represent the time interval which is believed to exist between the two formations.

AGE AND CORRELATION.

No fossils were found in the formation in Luna County, but the Bliss sandstone, which has the same character and the same relative position in the type locality in Franklin Mountains, near El Paso,

Tex., contains a few Upper Cambrian fossils. Its character and relations also indicate that it is the same as the "Shandon" sandstone of central New Mexico and the basal sandstone of the Silver City region.

ORDOVICIAN SYSTEM.

CLASSIFICATION.

In Luna County the Ordovician system comprises an extensive succession of limestones ranging in age from Beekmantown (early Ordovician) to Richmond. Portions of Ordovician time, however, apparently are not represented by deposits, so that there are unconformities between the formations. On the basis of lithology, fossils, and stratigraphic position the lowest limestone series has been correlated with the El Paso limestone of the El Paso quadrangle and the upper series has been correlated with the Montoya limestone of that quadrangle. In Fluorite Ridge and the Florida Mountains it is difficult to separate the upper beds of the Montoya from the Fusselman limestone, which is of Silurian age. Therefore these two limestones are mapped together on Plate I.

EL PASO LIMESTONE.

DISTRIBUTION AND CHARACTER.

The El Paso limestone appears at the surface at several widely separated localities in Luna County. It is conspicuous in the northern part of Cooks Range, in several areas in the Florida Mountains, in the east end of Fluorite Ridge, in the Snake Hills, and in the Klondike Hills.

It consists mainly of gray, slabby limestone and dolomitic limestone from 500 to 800 feet thick. This limestone begins at the top of the Bliss sandstone and terminates abruptly at the base of the Montoya limestone without notable discordance of dip. Portions of the El Paso limestone are slightly cherty, and some beds contain considerable sand or clay, but these are minor features. Pale-reddish elongated blotches on the bedding planes are characteristic of most beds, and the slabby bedding and light tint are also distinctive of the formation. Several of the exposures in the Florida Mountains exhibit all the beds of the formation, but in Fluorite Ridge some portions appear to be crushed out or faulted down. Small outcrops of the upper part of the formation appear at the west end of the two ridges west of The Park. The section west of Capitol Dome is complete with the Bliss sandstone below and the Montoya limestone above the El Paso, the formation having a thickness of about 800 feet and cropping out along the slope for about a mile. This area is terminated at the north by a cross fault that brings down agglomerate and at the south by a fault that brings up

the granite. The rocks are mostly the typical light-gray, slabby limestone in beds 2 to 6 inches thick, in part dolomitic and containing a small amount of chert, but the basal beds for about 140 feet are more massive and darker than at other places. The exposures east of The Park on the summit and western slope of the Florida Mountains show about 700 feet of beds lying on the Bliss sandstone and capped by the Montoya limestone or Gym limestone. To the south these beds are cut off by granite brought up by the great cross fault, and other smaller faults break the continuity of the exposures. The rocks here are similar to those at Capitol Dome, but the dark basal bed is absent. The formation is exposed extensively in the northern slope of Gym Peak ridge and in the outlying ridges on the north, underlying the Montoya limestone and cut off by several faults. Here its thickness appears to be fully 800 feet, and possibly more, notably in one long section of nearly vertical beds on the north side of the draw, slightly more than a mile northwest of the peak. A small mass is faulted against the granite just north of the road half a mile east of Byer Spring. In the slopes a mile southeast of that spring the formation includes a thick mass of chalcedony, apparently due to local replacement of some of the limestone, and other similar masses crop out along a fissure in the slopes east of The Park.

The El Paso limestone constitutes the central and eastern portions of the ridge of rounded knobs known as the Snake Hills, southwest of Deming. (See fig. 11, p. 88.) The strata here dip at low angles, and the total thickness of beds exhibited is not more than 700 feet. The lowest beds exposed at the east end of the ridge are made up of typical slabby light-gray limestone. These are overlain abruptly by the dark-colored massive limestone at the base of the Montoya.

The El Paso limestone crops out for nearly a mile in the high knob just west of Fluorite Camp, but the beds here are nearly vertical and the outcrop zone is very narrow. The Bliss sandstone is in contact with the limestone on the south and the Montoya limestone on the north, and the intervening ledges of El Paso limestone measure only 400 feet in thickness at the east end of the ridge and somewhat less at the west end. This small thickness is probably due to faulting and crushing along a plane or planes parallel to the obvious fault between the Bliss sandstone and the pre-Cambrian granite.

The outcrop of the El Paso limestone near the north end of Cooks Range is on the summit and the western slopes, where the beds appear in regular order between the Bliss sandstone and Montoya limestone in a succession, dipping gently to the south-southeast. The thickness is about 600 feet, and the rocks have the characteristics which they present in other localities.

The El Paso limestone constitutes a large part of the Klondike Hills, where it lies on the Bliss sandstone and is overlain by sandstone at the base of the Montoya limestone. Its thickness here is about 650 feet, and the beds present the characteristic light-gray color, slabby bedding, and pale-reddish markings on many of the bedding planes.

FOSSILS AND CORRELATION.

Fossils are scarce in the El Paso limestone, but those collected just west of Capitol Dome, in Fluorite Ridge, near Gym Peak, in the ridges east and west of The Park, in the Snake Hills, and in the Klondike Hills suffice to indicate its approximate age. These fossils were examined by E. O. Ulrich and Edwin Kirk, who found that most of them are a species of Ophileta, of Beekmantown or early Ordovician age.

Fossils found in the upper beds in the center of the Snake Hills were identified by Mr. Kirk as Dalmanella cf. *D. pogonipensis* H. and W. and Hormotoma sp. On the west slope of the Gym Peak were found, also in the upper beds, Strophomena near *S. nemea* H. and W., Hormotoma sp., and Trochonema sp. The brachiopods are close to forms described from the upper part of the Pogonip limestone of the Eureka and White Pine districts in Nevada and indicate late Beekmantown or possibly early Chazyan age. On the evidence of fossils, close similarity in rocks, and stratigraphic relations there is no difficulty in correlating the formation with the El Paso limestone of the type locality in the Franklin Mountains near El Paso, Tex. It also represents the greater part of what Gordon has called the Mimbres limestone of the region north of Luna County, but Gordon's Mimbres includes also the Fusselman and Montoya limestones.

MONTOYA LIMESTONE.

OCCURRENCE.

The Montoya limestone crops in the northern part of Cooks Range, in the northern and central parts of the Florida Mountains, in the Victorio Mountains, in the Klondike Hills, and in the Snake Hills. In all these areas the rocks are light-gray slabby limestone with highly fossiliferous layers, a large amount of chert, and at the bottom a dark-colored massive limestone or sandstone. The chert is a characteristic feature and gives considerable prominence to the outcrops. It occurs mostly in thin beds alternating with layers of limestone, and the greater part of it is in two thick members, with purer limestones above and below. The thickness of the formation varies somewhat, but the average amount is near 300 feet. As the

upper limit of the formation is not distinct in part of the area and the outcrop zones are narrow, the Montoya and Fusselman limestones are not separated on the geologic map (Pl. I, in pocket).

The largest area in the Florida Mountains are the three masses extending nearly across the range at The Park and Gym Peak, where the outcrop zone is repeatedly brought up by the faults. There the Montoya limestone lies on the El Paso limestone, but some of the faults bring it into contact with granite and other formations, and at several places the Gym limestone lies directly on its eroded surface. Elsewhere it is overlain by the Fusselman limestone, but the plane between the two formations is difficult to discern. On the west side of the summit the Montoya limestone crops out in irregular cliffs facing west, and a long exposure crosses the ridge just north of Gym Peak. Other outcrops appear in ridges west of The Park, and there is an outlier along the fault a mile southeast of Byer Spring. In this region, as elsewhere, cherty ledges are conspicuous features at two horizons, and the massive dark limestone occurs at the base.

The small mass of Montoya limestone in the slope west of Capitol Dome is overlapped unconformably by the Lobo formation to the east, north, and south. Here 145 feet of the formation was measured, comprising a 40-foot cherty member at the top, 30 feet of dark sandy limestone and 25 feet of cherty limestone in the middle, and 50 feet of dark massive limestone at the base.

The Montoya limestone constitutes part of the limestone ridge extending north from Cooks Peak. It rises from beneath the bolson at a point about a mile north of the main road forks, west of the mountain, and reaches the summit some distance farther north, where it is cut off by the great fault. The thickness of the beds at this place is about 250 feet, and the limits of the formation are well defined, as the overlying Fusselman limestone is distinctive in appearance. The top member consists of 60 feet of light-colored slabby limestones with 6 feet of very fossiliferous beds at the base. This is underlain by 150 feet of limestones with numerous thick and thin cherty layers, followed by a basal member 40 feet thick of dark-gray massive limy sandstone lying on El Paso beds.

The formation is extensively exposed in the high knob and ridge of the western half of the Snake Hills, beginning a short distance west of the main road. At the base is the usual dark-colored massive limestone. This is overlain by very cherty limestone with alternating layers of purer limestone. Next comes 30 feet of massive dark-gray sandy limestone giving rise to low cliffs and grading up into a purer, partly massive limestone which weathers to a dirty olive tint; then a 60-foot member of alternating layers of chert and

limestone, with fossils; and at the top, capping the highest butte on the ridge, a thick mass of very cherty rock. The thickness of beds classed as Montoya is 300 feet, and they extend to the bolson on either side and to the west without indication of the Fusselman limestone.

The formation is prominent in the hill west of Fluorite Camp on account of its conspicuous thick cherty layers. The beds dip steeply to the north, and are cut off by a fault to the east. (See fig. 10, p. 86.) At the base is a dark-colored massive limestone, as at other places. This is followed by cherty limestone, with the chert mostly in thin layers. Next above are finer slabby gray limestones with many fossils, and still higher is a thick body of highly cherty limestone. At the top is 50 feet of massive limestone of unknown age, possibly Fusselman, extending to or from a small fault which cuts the section in this vicinity and drops the Percha shale and associated beds for some distance. A short distance to the southeast there are several small but prominent ridges consisting of thick bodies of massive chert apparently replacing a limestone, presumably the Montoya, but as it is nearly surrounded by porphyry and displaced by faults its relations could not be ascertained.

The high buttes and east end of the Klondike Hills consist of the Montoya limestone. (See fig. 14, p. 92.) The beds dip east at a low angle and the outcrops are repeated by one or more cross faults. The basal member is dark-gray sandstone 6 to 8 feet thick lying on a slightly irregular surface of the El Paso limestone. It is followed by 30 to 40 feet of dark massive sandy limestone, as in other areas, and this gives place abruptly to the typical cherty beds of the Montoya limestone. There are two or possibly three cherty members, mostly alternations of thin beds of chert and pure olive-gray limestones with intervening layers of slabby gray limestone containing abundant fossils.

In the Victorio Mountains the Montoya limestone constitutes the north, east, and west slopes of Mine Hill, and the outcrop extends northwestward along the lower southern slopes of the range, as shown in figure 9 (p. 84). The strata in Mine Hill dip to the south at low angles, and about 300 feet of beds are exposed, but in the slopes on the west they dip to the north and are overlapped by or faulted against the Gym limestone. The basal beds are covered by bolson deposits in the gap north of Mine Hill, and the beds exposed in this hill are mostly dark-gray limestone with thick chert layers and intercalated light-colored beds containing many fossils of the Richmond fauna.

It is difficult to separate the Montoya from the overlying Fusselman on Mine Hill, and apparently the Fusselman is absent in the ridges to the west.

FOSSILS AND CORRELATION.

The Montoya limestone contains numerous fossils in considerable variety and in excellent state of preservation. The following species have been identified by E. O. Ulrich in material collected northwest of Cooks Peak, near Gym Peak, in Fluorite Ridge, in the Klondike Hills, and in slopes a mile northwest of the Victorio mining camp: Eurydictya cf. *E. montifera; Dinorthis subquadrata*, *Plectorthis whitfieldi*, *Hebertella occidentalis*, Dalmanella cf. *D. meeki*, Dalmanella near *D. jugosa*, *Platystrophia acutilirata* var., Strophomena cf. *S. subtenta*, *Rafinesquina loxorhytis* W. and S., *Leptæna unicostata*, *Plectambonites saxea*, *Rhynchonella anticostiensis* (*argenturbica* White), *Rhynchotrema capax*, *Zygospira recurvirostris*, Cyrtodonta sp., Vanuxemia sp., and Bumastus sp.

In beds between the two cherty members on the limestone knob west of Fluorite Camp were obtained Strophomena cf. *S. subtenta* Conrad, Platystrophia cf. *P. acutilira* Conrad var., *Rhynchotrema perlamellosa* Whitfield, and *Streptelasma rusticium* Billings. These fossils are characteristic of the Richmond fauna, which occurs in various portions of the Rocky Mountain region. No fossils were collected from the basal dark massive bed.

The paleontologic and lithologic evidence is ample for correlating the beds in Luna County, here designated Montoya limestone, with the Montoyo limestone in the type locality in the Franklin Mountain region south of El Paso, Tex.

SILURIAN SYSTEM.

FUSSELMAN LIMESTONE.

DISTRIBUTION AND CHARACTER.

The Fusselman limestone crops out at several localities in Luna County. One of the most notable exposures, on account of its fossils, is on the south slope of Mine Hill, at Victorio mining camp, and the formation is a conspicuous feature in the series of limestones in the ridge at the north end of Cooks Range. It overlies the Montoya limestone in most of the Gym Peak area and in the ridge northwest of Fluorite Camp, but it is much less characteristic at these places. In Cooks Range the typical rock is massive limestone of gray color and exceptionally hard, compact texture, about 200 feet thick, and it is the source of most of the lead, silver, and zinc ores. There it is overlain by the Percha shale. The thickness at Victorio and other places is difficult to determine because of lack of distinctive features defining the limits of the formation. It constitutes the south slope of Mine Hill. Near Gym Peak and The Park the dark slabby limestone above the Montoya yielded a few fragments of corals believed to be of Silurian age, but the rocks do not closely

resemble the Fusselman limestone of other areas. Moreover, the Percha shale is absent, so there is great difficulty in separating the Fusselman from the Gym limestone, which lies unconformably on the older limestones in this area. The conditions are somewhat similar west of Fluorite Camp, for although the Percha shale is present the succession is cut by a fault of undetermined amount which lifts the supposed Fusselman into contact with the Lake Valley limestone.

FOSSILS AND CORRELATION.

In the Cooks Peak district and near Silver City the Fusselman limestone contains large numbers of a distinctive Pentamerus, and in the south side of Mine Hill, in the Victorio Mountains, it carries corals as follows: *Heliolites megastoma*, Heliolites? sp. (very small corallites like *Lyella puella* Davis), Favosites cf. *F. venustus*, Favosites sp. (closely septate, cells larger than in *F. venustus*), Cyathophyllum cf. *C. radicula*, Heliophyllum sp., *Halysites catenulatus* (large and small varieties), and Syringopora sp. This is also an orthoid suggesting *Rhipidomella hybrida*. These were determined by E. O. Ulrich, who states that they represent a Silurian zone hitherto practically unrecognized in the Southwest. It probably corresponds to the late Niagaran of the Mississippi Valley and is slightly younger than the dolomitic Silurian containing Pentamerus in Cooks Range. Mr. Ulrich says: "The only other occurrence of a similar coral fauna in the far West known to me is that described by Dr. Kindle, who found it in southeastern Utah." On the basis of lithology, stratigraphic position, and fossils, these rocks in Luna County are correlated with the Fusselman limestone of the type locality in the Franklin Mountains, near El Paso, Tex.

DEVONIAN SYSTEM.

PERCHA SHALE.

A mass of black fissile shale lying between the Fusselman limestone and the Lake Valley limestone in Cooks Range lithologically resembles and is believed to represent the Percha shale, of which the type locality is in the Lake Valley mining district, not far north. No fossils were found, but the character of the material and its stratigraphic relations make the correlation reasonable. A small mass of similar shale a short distance north of Fluorite Camp is also believed to be the Percha shale. In Cooks Range the thickness is about 175 feet and the rock is a uniform black shale of moderate hardness separating into thin, brittle layers. It crops out extensively along the limestone slopes on both sides of the range northwest of Cooks post office, and there are two smaller exposures 2 miles east

and 3 miles southeast of Cooks Peak. The southern of these exposures lies between porphyry and the overlying Lake Valley limestone. The shale is conspicuous along the road up the mountain at Cooks post office, where it overlies the ore-bearing Fusselman limestone. Its outcrop extends through the gap over which this road passes and far down the hollow on the west slope of the range. It appears again between the Fusselman and Lake Valley limestones north of the road on the west side of the ridge, and its outcrop extends up the slope to the northeast and, passing over the summit, is finally cut off by the great fault on the east slope. (See fig. 3, p. 70.)

In Fluorite Ridge there are two small exposures a short distance northeast of Fluorite Camp, but they extend only a short distance and are terminated by faults and porphyry. Here the shale lies in regular order under the Lake Valley limestone, but is separated from the Fusselman and Montoya limestones by faults. The Percha shale appears to be absent in the Florida and Victorio mountains. Some black shale cropping out a mile south of Gym Peak closely resembles it in appearance, but seems to be included in a regular succession of beds of the Gym limestone; possibly, however, it is cut off by overlap or faulting. Some dark shale overlies the Lake Valley limestone 1½ miles southwest of Cooks post office, but it contains numerous Pennsylvanian fossils.

CARBONIFEROUS SYSTEM.

CLASSIFICATION.

In Luna County the Carboniferous system is represented by portions of the Pennsylvanian and Mississippian series, apparently separated by a hiatus of considerable amount, and it is probable that in each series there is not a complete sequence of the sediments which appear in other regions. There is also an overlap of the higher limestone toward the south, for in the Florida and Victorio mountains the later Carboniferous rocks lie directly on the Ordovician limestones, and the Mississippian and the earlier Pennsylvanian, or Magdalena, appear to be absent. The later Pennsylvanian or Manzano group is represented by a thick limestone formation, and a still younger formation, here separated as the Lobo and tentatively assigned to the Triassic (?), may possibly represent the upper part of the Manzano.

LAKE VALLEY LIMESTONE.

DISTRIBUTION AND CHARACTER.

The Lake Valley limestone consists of rocks that are mostly of light-gray color and have massive to slabby bedding. Some limy shales are included between the more massive bodies of limestone,

and at two localities dark shale members reach a thickness of nearly 100 feet. The thickness in the Cooks Range is between 600 and 700 feet, but the formation thins to the south and is absent in the Florida and Victorio mountains.

The most extensive exposures of the Lake Valley limestone in Luna County are in Cooks Range, where they constitute high ridges with prominent cliffs, nearly encircling the Cooks Peak igneous masses. Here the formation consists largely of gray limestone of light color and slabby bedding, lying on the Percha shale, except locally, where there has been intrusion of porphyry.

Most exposures in this region show a succession of massive cliffs of limestone 80 to 100 feet high separated by slopes of softer limy shale. The basal member consists of 150 feet of bluish-gray limestone with some chert in its lower portion. Next above is 50 feet of shale with layers of limestone, mostly very fossiliferous. The limestone constitutes the crest of the mountain west of Cooks post office and extends for some distance northward. In some places it is overlain by the Lobo formation, and in others it is cut off by faults or porphyry intrusions. It is extensively exposed in the deep canyons 2 miles south of Cooks Peak, where the Percha shale is overlain by 450 feet of limestone in three massive cliffs separated by steep slopes of limy shale. The upper cliff marks the outcrop of a body of hard limestone about 100 feet thick, which is overlain by the beds indicated in the following section:

Section of upper members of Lake Valley limestone, Gym limestone, and Lobo formation in Cooks Range just north of latitude 32° 30′ N.

	Feet.
Lobo formation:	
Conglomerate with limestone matrix	30
Shale, red	50
Conglomerate	10
Gym limestone:	
Limestone, nodule-bearing	5
Limestone, blue	20
Conglomerate, some red jasper	5
Lake Valley limestone:	
Limestone, cherty	3
Limestone, gray (Mississippian fossils)	3
Conglomerate or breccia of white chert	10
White chert with crinoid stems	20

The white chert lies on the massive limestone above mentioned and is a conspicuous bed in the ridges about Cooks Peak. The nodule-bearing limestone, blue limestone, and jasper-bearing conglomerate represent the Gym limestone, for the upper beds yield distinctive Manzano fossils on the west slope of the range. On the slopes southwest of Cooks Peak the cherty member is overlain by

black to gray shale with thin impure limestone layers that yielded Magdalena fossils in considerable abundance, indicating that this formation locally overlies the Lake Valley limestone.

In the southwest end of Fluorite Ridge, half a mile northeast of Fluorite Camp, the Percha shale is overlain by a small thickness of limestone containing Mississippian fossils. Some of the relations at this place are shown in the section given in figure 10 (p. 86). The beds are cut off within a short distance by faults and intrusive porphyry. It has been stated that the limestone at the zinc mine at the north end of the Tres Hermanas Mountains is of Mississippian age, but as the fossils noted there are not distinctive of that epoch of geologic time it is believed more probable that the beds belong to the Gym limestone.

FOSSILS AND CORRELATION.

The Lake Valley limestone contains large numbers of fossils in some places, notably in the exposures south, east, and north of Cooks Peak. A collection made in the cliffs 4 miles northwest of Fort Cummings was determined by G. H. Girty as follows: Endothyra? sp., *Leptæna rhomboidalis*, *Productus semireticulatus*, *P. lævicosta?*, Productus aff. *P. burlingtonensis*, Schuchertella sp., Paraparchites sp., and Bairdia sp. From exposures on the northward slope of Cooks Peak were collected Triplophyllum sp., Fenestella sp., *Schuchertella chemungensis*, *Productus lævicosta*, *Spirifer suborbicularis?*, *S. centronatus*, *Composita humilis*, Rhombopora sp., Cystodictya aff. *C. pustulosa*, and Cladochonus sp. Some of these forms were also collected at other points along the Cooks Peak road and the slopes on the north. These fossils indicate that the limestone belongs to the Mississippian series of the Carboniferous.

Near the top of the mountain 1½ miles northwest of Cooks post office were obtained Menophyllum sp., Fenestella sp., *Rhipidomella pulchella?*, Productus aff. *P. wortheni*, *Spirifer centronatus*, and Paraparchites sp., all Mississippian forms. In limestones overlying the Percha shale, half a mile west by south of Fluorite Camp, were found *Spirifer centronatus*, *Leptæna rhomboidalis*, Pinnatopora sp., and several species of Fenestella.

MAGDALENA FORMATION.

CHARACTER AND OCCURRENCE.

High in the slopes on the northwest side of Cooks Peak some dark shale intervenes between the nodular limestone of the Gym limestone and the white chert at the top of the Lake Valley limestone. This shale is not more than 40 feet thick and it appears not to be of great extent, for erosion has removed most of the sedimentary rocks in the

vicinity. It is of dark-gray color, but contains layers of limy shale and thin limestone, and in this respect differs from the Percha shale and the shale members in the Lake Valley limestone. Possibly it occurs in other portions of the area, but in exposures south and west of the peak chert and fossiliferous beds of the Gym limestone lie directly on top of the Lake Valley limestone.

FOSSILS AND CORRELATION.

This shale contains abundant fossils, which were determined as follows by G. H. Girty: Rhombopora sp., Lingulidiscina sp., *Derbya crassa*, *Chonetes mesolobus*, "*Productus semireticulatus*, *Pustula nebraskensis?*, *Marginifera muricata*, Pugnax sp., *Spirifer cameratus*, *S. rockymontanus*, *Ambocœlia planiconvexa*, Aviculipecten, 2 sp., *Acanthopecten carboniferus*, *Lima retifera*, *Astartella vera*, *Edmondia subtruncata*, Phillipsia aff. *P. scitula*. This fauna is regarded by Mr. Girty as early Pennsylvanian and as belonging to the Magdalena group.

GYM LIMESTONE.

DISTRIBUTION, NAME, AND RELATIONS.

In the central and southeastern portions of the Florida Mountains and the central portion of the Victorio Mountains and extending part way around the north end of the Tres Hermanas Mountains there is a thick series of limestones to which it is proposed to apply the name Gym limestone, from Gym Peak, where the formation is extensively exhibited. The formation constitutes the summits of the high ridges at and northwest of Gym Peak and the two ridges west of The Park, and it extends down and along the east slope of the mountain east of Gym Peak. In this vicinity the formation is in several large detached masses capping fault blocks and cut off to the southeast by the great fault which uplifts the granite in the southern part of the mountain. Several small outlying masses are intricately faulted into the granite in the lower slopes 2 miles south of Gym Peak. The thickness of the formation is near 1,000 feet. It lies on an unevenly eroded surface of the Montoya limestone and in places on the top member of the El Paso limestone. In the Victorio Mountains it lies on or is faulted against the Montoya limestone, and in the Tres Hermanas Mountains it is uplifted and cut by the granite porphyry.

Overlying formations are not exposed in the Florida and Tres Hermanas Mountains but in the Victorio Mountains the Gym limestone is overlain by supposed agglomerate. The formation appears not to crop out in Fluorite Ridge, but a thin representative underlies the Lobo formation in Sarten Ridge and along the flanks of Cooks Range.

CHARACTER AND LOCAL FEATURES.

The formation consists chiefly of limestone, in greater part massively bedded, of light-gray color and showing a brecciated structure in many beds. In Gym Peak and vicinity the lower member is dark and the one next above it is much lighter in color, with an abrupt change from one to the other, and the thickness remaining in this area and west of the peak is at least 700 feet. In the canyon 1 mile southeast of Gym Peak limestone apparently in the middle of the formation dips steeply southeastward under 80 feet of dark-gray fissile shale which is traceable for about half a mile and again appears along the great fault on the trail a short distance west of Gym Peak. This black shale is overlain on the east by cherty limestone containing abundant Manzano fossils and this limestone is finally cut off by the great fault which crosses the mountain. To the east the Gym limestone of this area passes beneath the bolson deposits. In the outlier 2 miles south of Gym Peak the rock is a light-colored massive limestone weathering dark gray and containing many fossils. In the mass lying farther southwest the limestone lies in part on the coarse granite and in part on gray quartzitic sandstone about 12 feet thick, the sedimentary rocks apparently overthrust onto the granite. A few rods east and northeast of this outlier are several large irregular masses of the limestone, upon and into which the granite has been faulted with relations described on pages 73–75.

At the north end of the great mass of porphyry of the Tres Hermanas Mountains there are two extensive outcrops of the Gym limestone, separated by the large draw draining the north slope, and another area constitutes the westernmost ridge of the range. About the old zinc mines the limestones constitute a low ridge, in which the beds dip to the north and northeast at low angles. Along the porphyry contact the limestone is metamorphosed to marble and the more impure portions to hornfels. Two miles farther east the limestone appears again, flanking the porphyry for a mile or more and constituting a ridge of considerable prominence, which is a spur of the highest peak of the range. Here the beds dip to the northeast and north, and the limestone passes under gray quartzite, which is the highest member exposed. Marble appears at the porphyry contact, and several masses of this altered rock are included in the porphyry. The limestone extends for several miles along the eastern slope of the high peaks of these mountains, in some places in contact with porphyry and in others cut by rhyolite and keratophyre. It dips mostly to the east and southeast at low angles and 500 to 600 feet of beds are exposed, some of them very fossiliferous. Here also the limestone at the porphyry contact is largely metamorphosed to coarsely crystalline white marble, and some of it is included in the

igneous body, notably one very large mass on the east slope of the southernmost of the three high peaks constituting the high northern ridge. The limestone in the westernmost ridge of the Tres Hermanas Mountains, west of the Hancock mine, overlies gray to red quartzite, of which 50 to 60 feet is exposed. The strata all dip to the west and over 400 feet of limestone is visible, some of which yields distinctive fossils. The quartzite appears to be the same as that overlying the limestone on the north side of the mountains, 2½ miles east of the zinc mines. Its relations on the east are hidden by igneous rock.

In the Victorio Mountains the Gym limestone constitutes the higher parts of the three limestone peaks south of Victorio Peak and extending for about a mile along a northwesterly course. It appears to lie on the Montoya limestone, but some Fusselman limestone may intervene. The lower beds are dark-gray limestone, partly brecciated, and the upper beds comprise slabby gray limestones.

The two small limestone knolls rising out of the bolson halfway between Tomerlin and the Tres Hermanas Mountains yielded Pennsylvanian fossils and are supposed to be Gym limestone continuous underground with the western ridge of the Tres Hermanas area, which strikes toward them.

The prominent limestone ridges 10 miles northeast of Arena, in T. 27 S., R. 5 W., present a series of beds dipping 15°–20° WSW. and exposing fully 400 feet of strata. The only fossil obtained here was a pelecypod resembling Schizodus and probably of Pennsylvanian age.

The Gym limestone in Sarten Ridge and Cooks Range appears as the beds rise from the great fault 4 miles northwest of Fort Cummings and extends across the range in the high northward-facing ridge 2 miles south of the peak. It is cut out by porphyry southwest of the peak, but comes in again northeast of the 55 ranch and is also exposed under the sandstone knobs to the north and east. It underlies a wide area of the cuesta east of Cooks post office and crops out in the cliffs on the north and northeast sides of this cuesta. In all this area it lies between the cherty limestone supposed to mark the top of the Lake Valley limestone and locally the black shale of the Magdalena formation and a 10-foot bed of conglomerate underlying red shale of the Lobo formation. Its total thickness here is only 25 to 30 feet, comprising 5 feet of nodular limestone at the top, 20 feet of blue limestone, and a 5-foot bed of conglomerate with some red jasper, which probably marks the base of the formation. The limestone contains abundant Manzano fossils at various places, notably in a gulch half a mile northeast of the 55 ranch. Possibly a small amount of the top of these beds appears in the Goat Ridge uplift and in the draw just north of the sandstone quarry a mile south of Fryingpan Spring. A small displaced wedge of the limestone is

exposed along the fault a few rods northeast of this quarry, lying on conglomerate a few yards east of the road.

FOSSILS AND CORRELATION.

Fossils were found in various parts of the Gym limestone, and while most of them are stated by G. H. Girty to be distinctive of the Manzano group of the Pennsylvanian series they do not afford a sufficiently definite basis for correlation with any formation of that group in central New Mexico, nor do they indicate how much of the group is represented. Some of the gastropods strongly suggest the Hueco fauna.

In the small mass of limestone faulted into the granite on the south side of the Florida Mountains, 2 miles south of Gym Peak, were obtained Fusulinella sp., *Productus semireticulatus*, *Pugnax utah*, *Composita subtilita*, Astartella? sp., Bellerophon aff. *B. crassus*, Pleurotomaria sp., Euomphalus aff. *E. pernodosus*, Meekospira sp., and Orthonema sp., determined by G. H. Girty.

Fossils were obtained near the base of the formation west of Gym Peak, from beds above the black shale member southeast of Gym Peak, in the Victorio Mountains, from the nodular limestone east of the 55 ranch, from the beds east of the middle part of the Tres Hermanas Mountains, from the limestone ridge on the west side of the Tres Hermanas Mountains, and from the outliers east of Tomerlin. The following species from the beds over the black shale southeast of Gym Peak were determined by G. H. Girty: *Chonetes platynotus?*, *Marginifera splendens?*, *Echinocrinus ornatus*, *Bellerophon crassus*, and Phymatifer n. sp. Phymatifer n. sp. was also found in the area east of Tomerlin.

From slightly higher beds a short distance farther southeast of Gym Peak the following were collected: Fusulinella sp., sponge and sponge spicules, *Echinocrinus ornatus*, Productus aff. *P. semireticulatus*, Ambocœlia? sp., Composita sp., *Parallelodon politus?*, Astartella sp., *Plagioglypta canna?*, *Bellerophon crassus* var. *wewokanus?*, *Bucanopsis modesta*, *Pleurotomaria texana*, Pleurotomaria 3 sp., Murchisonia 4 sp., Discohelix? n. sp., *Rhynchomphalus obtusispira*, Sphærodoma aff. *S. humilis*, Sphærodoma aff. *S. primigenia*, Cyclonema sp., Glyptobasis? sp., *Orthonema socorroense?*, Orthonema sp., Pseudomelania? 4 sp., Zygopleura n. sp., Loxonema? 2 sp., and *Bulimorpha inornata*.

Echinocrinus ornatus was also collected from the Gym limestone near the Mahoney mine.

In a bed near the middle of the Gym limestone half a mile south of Victorio Peak the following species were obtained: Solenomya? sp., *Nucula levatiformis*, *Nucula levatiformis* var. *obliqua*, *Manzanella*

elliptica, Edmondia sp., *Monopteria marian?*, Myalina sp., Schizodus sp., Pleurophorus sp., Astartella n. sp., *Plagioglypta canna?*, Murchisonia n. sp., Euomphalus? sp., Cyclonema? sp., and Sphærodoma? aff. *S. fusiformis*. In a bed somewhat lower in the formation exposed in the same draw were collected *Manzanella elliptica*, Astartella n. sp., Schizodus sp., Murchisonia n. sp., Naticopsis sp., and a number of undeterminable pelecypods.

In the extensive series exposed at the foot of the middle peak of the Tres Hermanas Mountains were collected *Meekella mexicana?*, *Productus cora*, *Composita mexicana?*, *Pinna peracuta*, *Bellerophon majusculus?*, and Euomphalus sp. In the beds on the ridge west of the Hancock mine, on the west side of the Tres Hermanas Mountains, were obtained *Productus occidentalis*, Productus sp., and *Squamularia perplexa*. These were all determined by G. H. Girty, who calls attention to the fact that the *Productus occidentalis* is a form characteristic of the limestone capping Sacramento Mountain at Cloudcroft, a bed which is very high in the Carboniferous.

The upper nodular limestones of the formation in slopes east of the 55 ranch southwest of Cooks Peak yielded Productus sp., *Composita subtilita*, and Euomphalus sp.

TRIASSIC (?) SYSTEM.

LOBO FORMATION.

RELATIONS AND NAME.

The shales, conglomerates, and impure limestones, herein designated the Lobo formation, lie unconformably on the Gym and older limestones and are unconformably overlain by the Sarten sandstone of the Comanche series in the Cooks Range region and by agglomerate in the Florida Mountains. They are called the Lobo formation from Lobo Draw, on the east slope of the Florida Mountains, where the rocks are extensively exposed. The thickness of the formation at that place is about 350 feet.

DISTRIBUTION.

The outcrop of the Lobo formation extends for about 5 miles in the higher slopes of the northern third of the Florida Mountains, which it crosses on a general northwesterly course. It lies on the Montoya and El Paso limestones to the north, but at Capitol Dome it overlaps granite uplifted by a pre-Lobo fault. From that place as far as it is exposed to the southeast it lies directly on a planation surface of granite. It is overlain by the agglomerate throughout this mountain range, and, while there is an apparent erosional unconformity at the contact there is no great discordance in dip.

Apparently the same formation appears again in the northeast face of the high ridge of Sarten sandstone in Cooks Range and in small outcrops on Goat Ridge and Fluorite Ridge. A small exposure is revealed in the deep hollow near the south end of Sarten Ridge, just north of the sandstone quarry. A closely similar formation lies between the andesite and the Gym limestone on the south side of the main high ridge of the Victorio Mountains, but as it includes conglomerates containing andesites and other eruptive rocks believed to be younger than Lobo, the deposit is regarded as part of the great agglomerate series.

CHARACTER AND THICKNESS.

The Lobo formation consists largely of reddish and gray shale and gray to pinkish impure limestone, but it includes much conglomerate at its base. In its overlap on the granite southeast of Capitol Dome there is some basal arkosic sandstone. A section on the west slope of Capitol Dome, beginning at the unconformity at the base of the agglomerate, is as follows:

Section of Lobo formation at Capitol Dome.

	Feet.
Sandstone, soft, reddish, with a few thin conglomerate layers and some limy beds (top)	50
Conglomerate, light colored, with limestone pebbles	8
Sandstone, pink, soft, with conglomerate streaks	30
Limestone, slabby, in bodies 3 to 10 feet thick, separated by buff and reddish shale with thin limestone layers; limestones weather buff	180
Shale, dark reddish	20
Limestone, massive, impure, with scattered pebbly streaks	10
Limestone, conglomerate, coarse, with chert and quartzite pebbles, red-sand matrix (bottom)	20
	318

The conglomerate lies on an irregularly eroded surface of the Montoya and El Paso limestones, but the dips of the three formations, as well as that of the overlying agglomerate, are all to the east at angles from 18° to 20°. A few rods southeast of the base of Capitol Dome the formation extends across the fault shown in figure 6 (p. 77), which lifts the granite to the level of the top of the El Paso limestone, a displacement of 1,000 feet or more. This feature indicates that the block, uplifted by this fault, was eroded to a plane before the deposition of the Lobo beds. Some of the limestone beds in the Lobo formation closely resemble lithographic stone but are harder and contain only 27 per cent of calcium carbonate, the remainder consisting of about 10 per cent of magnesium carbonate and of matter

insoluble in acid. At the typical locality in Lobo Draw the formation consists largely of buff and red shale and massive, very fine grained sandstone and limestone.

In the Cooks Range exposures the formation is thinner and presents certain differences in stratigraphy but no more than might be expected in a formation of this character. A section measured at the north end of Sarten Ridge, at a point 4 miles northwest of Fort Cummings, is as follows, beginning at the first bed below an apparent marked unconformity at the base of the Sarten sandstone:

Section of Lobo formation and underlying strata at north end of Sarten Ridge.

	Feet.
Lobo formation:	
Sandstone, snuff-colored	20
Conglomerate with limy matrix	25
Shale, red	40
Conglomerate	10
Gym limestone:	
Limestone, nodular, in red shale	5
Limestone, blue	20
Conglomerate, with some red jasper	5

The three beds at the base of this section doubtless represent the Gym limestone, for the nodular bed contains Manzano fossils on the west slope of the range.

AGE AND CORRELATION.

No fossils were found in the Lobo formation, so that its age is not determined. In the central part of Cooks Range it lies unconformably on the Gym limestone, of late Pennsylvanian age, and is also separated from the overlying Sarten sandstone (Lower Cretaceous) by an unconformity; hence its age may be Pennsylvanian, Permian, Triassic, or even earliest Cretaceous. Because of its unconformable relations with both the overlying and underlying formations, however, the Lobo is tentatively classified as Triassic (?).

CRETACEOUS SYSTEM.

CLASSIFICATION.

In Luna County the Cretaceous system is represented by Lower Cretaceous rocks carrying Washita and Trinity fossils and by the Colorado shale, of Upper Cretaceous age, the intervening formations apparently being absent, and higher formations being either absent or hidden beneath much later deposits.

Rocks of Washita age crop out extensively on the flanks of the central part of Cooks Range, in Fluorite Ridge, and in Goat Ridge northwest of China Tank. Limestones apparently of somewhat

lower position in the Comanche series constitute the prominent buttes at the north end of Sierra Rica, in the southwest corner of the county (Pl. VII, *A*, p. 15). In the region north of Deming the rocks are mainly hard massive sandstone, for which the name Sarten sandstone is proposed.

LIMESTONE OF COMANCHE AGE.

CHARACTER AND RELATIONS.

The ridges constituting the northern extension of the Sierra Rica, in the extreme southwest corner of Luna County, consist of limestones of Comanche (Trinity) age. They are similar to the Mural limestone, described by Ransome in the Bisbee folio, but it is thought undesirable to correlate them at present. In the lower slopes of these hills, at the International mine, there are alternating beds of limestone and limy shales, apparently of Washita age, which dip toward the buttes, but are doubtless separated from them by a fault. The greater part of the area is shown in Plate I (in pocket). The limestone of the buttes is a rock of light blue-gray color, in part massive and in part thin bedded. About 400 feet of it is exposed, and the beds dip to the north at a low angle. On the southeast slopes are limy shales and alternations of shale and limestone containing many fossils. The ledges of these rocks extend to the International mine, northeast of which there are ledges of gray quartzite, apparently at a lower horizon, but possibly separated by a fault.

FOSSILS AND AGE.

Fossils were collected in the limestone along the south slopes of both of the larger limestone ridges at the north end of Sierra Rica. They were determined by T. W. Stanton as a small terebratuloid, apparently closely related to *Kingena wacoensis* Roemer, which is common in the Comanche series, and the foraminifer *Orbitolina texana* (Roemer), which is characteristic of the Trinity group of the Comanche series. The former are very abundant. These fossils indicate a horizon the same as or near to that of the Mural limestone of the Bisbee quadrangle.

Impure limestone and shaly beds exposed in the flats just southeast of these ridges, a short distance north of the International mine, contain Ostrea, Corbula, Anchura, Turritella, and a few other fossils, including a great number of large Exogyras related to *E. quitmanensis* (Cragin), which are believed to be of Washita age. This evidence of fossils indicates that there is a fault between the limestone ridges yielding Trinity fossils and the flats where the Washita fossils were obtained.

SARTEN SANDSTONE.

OCCURRENCE AND RELATIONS.

The most extensive exposure of the Sarten sandstone is in the prominent southern extension of Cooks Range, known as Sarten Ridge, and the name, which is used here for the first time, is taken from that locality. Fluorite Ridge is also capped by the rock, and it is brought to the surface in the dome-shaped uplift of Goat Ridge. It constitutes the high cuesta or sloping plateau north and east of Cooks post office and appears in several knobs and ridges adjoining the porphyry of the Cooks Peak intrusion south of that post office and east and south of the 55 ranch. Most of these areas are cut off by faults or igneous rocks, and some of the outcrops slope down into the agglomerate of the bolson. At the north end of Sarten Ridge, in the Cooks post office area, in Goat Ridge, and in a canyon on the southeast side of Sarten Ridge the Sarten sandstone is exposed, lying without notable discordance of dip on the Lobo formation, which shows but slight evidence of erosion.

In the Pony Hills, north of Fluorite Ridge, the sandstone lies directly on or against granite, but apparently this relation is due to faults. In the eastern slope of the Pony Hill area a separating fault is well exposed. Some of the relations at this place are shown in figure 11 (p. 88).

At four localities south, southwest, and east of Cooks Peak and half a mile south of the 55 ranch the Sarten sandstone is overlain by Colorado shale without discordance of dip or other evidence of unconformity to represent the long interval between Washita and Colorado time.

CHARACTER AND THICKNESS.

The Sarten sandstone consists almost entirely of light-gray, massive sandstone, most of it quartzitic or very hard. Some beds are slabby and a few of them contain a little calcium carbonate. At the base there is more or less conglomerate, part of it containing angular and subangular fragments. The thickness of the formation in Sarten Ridge, Goat Ridge, and the ridges east of Cooks post office is 300 feet, but in many areas the top has been removed by erosion or covered by later deposits. Faults and porphyry cut off the lower beds in various places.

FOSSILS AND CORRELATION.

Most portions of the Sarten sandstone are barren of fossils, but some beds contain them in abundance and in excellent state of preservation. This is notably the case in the east slopes of Sarten Ridge about a mile north of Fryingpan Spring, where limy beds not far

below the middle of the formation yielded the following forms: *Cardita belviderensis* Cragin, *Cardium kansasense* Meek, *Protocardia texana* Conrad, *P. quadrans* Cragin, *Tapes belviderensis* Cragin?, Turritella aff. *T. seriatim-granulata* Roemer, Ostrea sp., Nucula sp., Trigonia sp., Lunatia sp., Cyprimeria sp., and Anchura sp. These were determined by T. W. Stanton, who states that they represent the forms of the Washita group of the Comanche series and show about the same faunal facies as that found in the marginal deposits of southern Kansas and near Tucumcari, N. Mex. The following fossils, obtained in the west end of Fluorite Ridge at apparently about the same horizon as at the locality northwest of Fryingpan Spring, were determined by Mr. Stanton: Ostrea sp., Trigonia sp., Leptosolen sp., Homomya sp., and Turritella sp.

COLORADO SHALE.

DISTRIBUTION.

The Colorado shale crops out at three places in Luna County, two of them in the north edge of the structural and topographic basin west of Fryingpan Spring and the other in a small syncline 2 miles southwest of Cooks Peak. The outcrops are small, but probably the shale underlies a large part of the basin north of Goat Ridge, and there may be much of it under the great bolson deposits in other parts of the country. The most extensive outcrop is 2½ miles northwest of Fryingpan Spring, where the shale occupies an area of nearly 1 square mile and the strata dip gently to the southwest. To the east are slopes of the Sarten sandstone, and at the north the shale is cut off by a large mass of porphyry intruded near its base. To the south and west the shale passes beneath bolson deposits and agglomerate, but it rises again with steep dip in a narrow outcrop zone along the foot of the Sarten sandstone ridge which lies 4 miles south-southwest of Cooks Peak. The exposures 2 miles southwest of Cooks Peak are mainly in a small low mound along a draw a few rods east of the main north and south road. Here the beds lie in a local deepening of a syncline of the Sarten sandstone. A narrow area of Colorado shale extends along the foot of the mountain east of Cooks Peak from Cooks post office to the south line of T. 20 S. It lies on the Sarten sandstone in part in a syncline and cut off on the west by the fault. It is also cut off on the southeast by a fault separating it from the agglomerate series.

CHARACTER AND RELATIONS.

In the easternmost area above described there are about 200 feet of beds exposed. They consist mainly of dark shale with interbedded layers of sandstone and sandy shale and several thin beds

of dark blue-gray limestone which weathers to a dirty buff color. The uppermost shale is darker than that below, and a few feet of slabby buff sandstone appears at one point where the formation passes beneath the overlapping agglomerate. The shale is separated from the underlying Sarten sandstone by abrupt change in character of materials, but there is no noticeable discordance of dip, and coarse fragmental sediments are lacking. There is probably at this horizon a hiatus representing the Dakota sandstone and associated beds, covering a considerable portion of early Upper Cretaceous time.

FOSSILS AND AGE.

Numerous fossils occur in the Colorado shale at all outcrops. The following were determined by T. W. Stanton: *Gryphæa newberryi* Stanton, *Inoceramus labiatus?* Schlotheim, Metoicoceras sp., and Prionotropis sp. These forms all belong to the Benton fauna. The little Gryphæas weather out in large numbers from some of the beds and accumulate on the surface. One limestone layer near the middle of the beds exposed contains many scattered cephalopods, which are difficult to obtain in good condition.

Fossils are numerous in a sandy layer at the eastern margin of the outcrop zone 2 miles west-southwest of Wallace's ranch, each of Cooks Peak. At this place the following were collected: Ostrea sp., Gryphæa? sp., Modiola sp., Astarte sp., Veniella? sp., Anatina? sp., Corbula sp., *Glauconia coalvillensis* (Meek)?, Volutoderma? sp., and Fasciolaria? sp. They were determined by T. W. Stanton, who regards them as Upper Cretaceous. They are casts, and several appear to be undescribed species.

TERTIARY SYSTEM.

AGGLOMERATE AND ASSOCIATED ROCKS.

CHARACTER AND RELATIONS.

In Luna County the Tertiary system is represented mainly by a great thickness of irregularly stratified, nonfossiliferous deposits, chiefly of volcanic origin and pyroclastic character, interbedded with intrusive sheets and volcanic flows. The material consists of agglomerate, tuff, volcanic ash, flows of volcanic mud, and some flow breccias. The greater part of the finer material was wind borne, but portions have been deposited or rearranged by water. Some beds of sand, sandstone, gravel, and conglomerate of ordinary detrital origin are also included. The thickness of the deposits is more than 2,000 feet, and as they are extensively exposed in nearly all the ridges it is probable that they also underlie a large part of the bolson areas. They lie unconformably on various formations up

to and including the Colorado shale, of middle Upper Cretaceous age, and are regarded as Tertiary, although the lower part may be late Cretaceous, and some of the beds at the top may be of Quaternary age. They are overlain unconformably by the Quaternary bolson deposits. The thick sheets of volcanic flows of various kinds which are interbedded at intervals in parts of the area were the products of intermittent volcanic eruptions. The deposits are also cut by dikes, some of them the feeders of the eruptive flows.

The typical agglomerate, which is the predominating deposit, is a massive rock, mostly very hard, made up of angular masses of eruptive rocks, chiefly dark-gray andesite or purplish latite embedded in a matrix of tuff or ash. In places the matrix is crystalline and the rock is probably of a flow breccia. There are also mud flows and thin sheets of lava, which have flowed over the unconsolidated deposits and become mixed with a large amount of fragmental ejected material. Accumulations of tuff and other volcanic materials deposited in part, at least, by water are of common occurrence, including irregular bodies of volcanic ash of considerable thickness and extent. Some of the water-laid material consists of ordinary sand and gravel, the detritus of various rocks, sedimentary and volcanic, now mostly hardened to sandstone or conglomerate, but in some places difficult to distinguish from the bolson deposits.

DISTRIBUTION.

The most extensive exposures of the pyroclastic rocks are in the north end of the Florida Mountains, the crest and east side of the Little Florida Mountains, the east side and south end of Cooks Range, the wide area northeast of Cooks Range, the Carrizalillo Hills, the Cedar Grove Mountains, the southeast and northeast slopes of the Tres Hermanas Mountains, the west slope of the Goodsight Mountains, the Fourmile Hills and Taylor Mountain area, the valley of the Mimbres above Taylor Mountain, and under the andesite in the Victorio Mountains. Smaller exposures occur about Fluorite Ridge, on Goat Ridge, at the south end of the Burdick Hills, at a few points about the Cow Spring Hills, and in the southwest corner of T. 27 S., R. 5 W. There is a very small outcrop on the south side of Red Mountain. Ash and gravel under the basalt of Black Mountain are classed with this formation, but may be somewhat younger than the main body of agglomerate in other areas.

LOCAL FEATURES.

The agglomerate forming the rugged peaks and deeply dissected slopes of the north end of the Florida Mountains exhibits the relations shown in the sections in figure 3 (p. 70). The thickness ex-

posed is about 1,600 feet, but as a portion has been removed by erosion, doubtless there is more of it under the bolson east of the mountains. It lies unconformably on the Lobo formation, but without notable discordance in the dip, which is at a low angle to the east and northeast. Much of the agglomerate in the Florida Mountains is a hard gray rock in massive beds, which are 50 to 80 feet thick in many places. These beds consist mostly of large angular fragments of andesite and other contemporaneous eruptive rocks in a matrix of partly crystalline nature. Toward the base at Capitol Dome there is an alternation of less massive beds, as follows:

Section of pyroclastic rocks at Capitol Dome.

	Feet.
Agglomerate, very massive, purplish gray	150
Sandstone, gray to reddish	4
Conglomerate, coarse, bowlders 1 to 6 inches, mostly volcanic rock, but some blue limestone and coarse reddish granite	30
Sandstone slabby, light dirty green, made up mostly of comminuted volcanic rocks	12
Conglomerate, coarse, bowlders, largely volcanic rocks, some blue limestone and coarse red granite	10
Agglomerate, massive, fine grained, and tuff full of small angular fragments of eruptive rocks (andesite, etc.)	50
Keratophyre flows, slabby to massive, gray, fine grained, with beds of andesite tuff in layers of varying thickness, some showing mud cracks	40
Agglomerate, with rounded to subangular masses of andesite, bedded	25
Keratophyre flow, gray, slabby, fine grained	3
Conglomerate, coarse, with rounded bowlders of andesite, limestone, granite, etc	20

The basal bed lies unconformably on 50 feet of soft reddish sandstone of the Lobo formation, and, although there is some evidence of erosion at the contact, there is no noticeable difference in direction or rate of dip. In places the middle and upper members of the series contain finer-grained beds, such as the body of fine-grained light-colored tuff that has been quarried for building stone on the east end of a spur 2 miles northeast of Arco del Diablo. The agglomerate in the faulted block 1½ miles southeast of Arco del Diablo is capped by a thin sheet of hornblende-augite andesite considerably leached and carrying masses of epidote.

The agglomerate in the Little Florida Mountains has the relations shown in figure 7 (p. 78). Part of it underlies the great sheet of felsitic rhyolite, but the greater part lies above that sheet and dips gently eastward down the east slope of the range. Presumably this body is at a higher horizon than the agglomerate in the Florida Mountains, but nothing could be ascertained as to the relations

owing to the covering of bolson deposits in the intervening gap. The agglomerate above the rhyolite is a massive deposit of dark-reddish coarse angular to subangular fragments, some of them 4 feet in diameter. This rock gives rugged topography to the top and west slope of the mountains, notably in the deep canyon just north of Black Rock. The coarse deposit thins greatly at the low pass across the range toward its north end. Possibly it gives place to finer sediments, for volcanic tuff and ash are exposed in slopes just east of the northern ridge of the mountains. The deposits exposed underlying the main igneous flow are mostly tuff and volcanic ash, in places considerably silicified.

A thick succession of agglomerates, tuffs, ash beds, and eruptive sheets is exposed in the various ridges constituting the south end of Cooks Range. It is cut off on the west by the great fault and on the east it passes beneath the bolson deposits. Besides the igneous materials the series includes sandstone and sand, and some of the fragmental material of igneous origin or nature has been deposited by water. Some brecciated mud flows are included, probably the edges of the larger eruptive sheets or small separate extrusions. The beds are all uplifted to moderately high angles, so that the general order of succession is exhibited from southwest to northeast. It begins with a thick series of agglomerates and ash including some sandstone that is prominent in two high buttes 3 miles northwest of Mirage Siding, where the rock is a red quartzite. In the next series of ridges to the north there is tuff overlain by several sheets of andesite and latite; then follow quartz basalt and hornblende-mica rhyolite interbedded in gray agglomerate and beds of volcanic ash. The succession is irregular, but some of the beds of fragmental rocks and igneous sheets crop out continuously for 5 to 6 miles along the strike. The thicknesses vary greatly, however, especially that of the bodies of volcanic ash, which thicken and thin within short distances.

Extensive exposures of fragmental volcanic rocks of various kinds appear about the foot of Fluorite Ridge, Goat Ridge, and the south slope of Cooks Range west of Sarten Ridge. They include some agglomerate and many beds of ash and tuff, and also of sandstone composed mostly of grains of volcanic rocks.

The material under the basalt cap of Black Mountain is largely waterlaid, but it consists mainly of rocks of volcanic origin, beds of ash, and more or less tuff. In all, about 400 feet of these materials lie above the level of the bolson at the south end of the mountain. The eastward dip of their own bedding and also of the basalt cap carries them beneath the surface to the east.

The agglomerate series in the Victorio Mountains lies on the Gym limestone and is overlain by andesite. The dips are somewhat

west of north at angles close to 20° throughout, and the thickness of the deposit is about 700 feet. There is no great difference in attitude between the agglomerate and the limestone. The younger formation begins with red sandstone and reddish to purplish-brown shale, with included conglomerate deposits. Some of the conglomerate is very coarse and contains pebbles and bowlders of andesites and other volcanic rocks, and it is because of this evidence that the formation is not correlated with the Lobo formation, which it closely resembles in all other respects. Near the top are green sandstones and coarse conglomerates with limestone pebbles, some containing Carboniferous fossils. Dark purplish-brown fine-grained massive shale or sandstone is the predominating rock in the formation in this region. Some of the dark beds contain considerable calcium carbonate.

The tuff at the Mimbres Dam site is a white massive rock near rhyolite in composition, in which the groundmass is probably albite.

A tuffaceous agglomerate of rhyolitic composition constitutes part of Taylor Mountain. It is a light-pink rock of medium density containing fragments of pumice and small, apparently waterworn pebbles, showing the fragmental character of the rock. The microscope reveals fragments of quartz and cloudy microcline, or microcline and quartz, as well as of various kinds of aphanitic rocks, embedded in a matrix consisting of angular pumice and a formless mass of nearly isotropic character, doubtless fine ash. The fragments of quartz and microcline, particularly the latter, are most certainly derived from a granite. The whole agglomerate is probably a reworked tuff in which granitic sand became incorporated.

A rock of almost exactly similar character is found 3 miles northeast of Taylor Mountain, along the side of Mimbres Valley. A short distance farther east, near the Grant-Luna county line, there is a white rhyolitic tuff showing distinct stratification. It is overlain by a sheet of pink rhyolite bearing numerous fragments of pumice, and this in turn is overlain by andesite.

The exposure of agglomerate at the foot of the south slope of Red Mountain extends only a few rods and is but a few yards in width. The material is a typical agglomerate with angular fragments, largely of dark purplish-gray rock, apparently hornblende-augite latite, in a matrix of finer material of the same general character. A low mound of bluish-gray agglomerate rises above the bolson on the south point of the Burdick Hills, 5 miles southwest of Iola. It is cut by dikes of various kinds, one of latite and another of quartz porphyry 10 feet wide.

AGE.

The agglomerates and associated rocks have yielded no fossils. To judge by their relations here and in adjoining areas they were accumulated during Tertiary time and probably in the later part of that period. Possibly the agglomerate is later than the porphyry intrusions, but no fragments of the porphyry have been observed in the agglomerate, and at one or two points in Cooks Range some features suggest that the agglomerate is cut by porphyry dikes. The time of deposition of the upper members of the agglomerate series may have continued into the Quaternary, for the relatively young basalts lie on volcanic ash and tuff deposits, and the earliest of the agglomerates may be as old as late Cretaceous.

QUATERNARY SYSTEM.

BOLSON DEPOSITS.

Luna County contains many thick deposits of sand, gravel, and clay of Quaternary age. In greater part they underlie the wide bolsons, and their smooth top surfaces are not incised very deeply by the present streams. Along the lower flats are accumulations of recent alluvium, but these can not be separated from the older deposits. Some portions of the alluvium consist of loose sand which blows from place to place, giving rise to local sand dunes, a feature mainly confined to the country along Mimbres River near Deming and the sandy slopes northeast of Arena. More or less of the talus accumulating on the slopes of hills and mountains is of Quaternary age, but its limits are too indefinite for representation on the geologic map.

The thickness and character of the deposits in the great bolsons between the mountains is known at certain localities from well borings, a few of which have reached the "bedrock." A deep hole bored in Deming. in 1887 entered rock at 963 to 980 feet, having passed through a succession of clay, sand, "cement," and gravel in alternating deposits 5 to 18 feet thick. The detailed record of a 950-foot boring at Lenark, a station on the Southern Pacific Railroad 60 miles east of Deming, shows a succession which is probably characteristic, although possibly some of the materials reported as sand and clay may be soft sandstone and shale of Cretaceous or Tertiary age. The following is the record as given by the driller, H. F. Gansirer:

Record of deep boring at Lenark, N. Mex.

	Thickness.	Depth to base.		Thickness.	Depth to base.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Red soil	13	13	Sand	106	562
Chalky clay	2	15	Red clay	28	590
Sandrock, hard	63	78	Yellow clay	50	640
Cemented stones	47	125	Sandstone, soft	26	666
Red clay	61	186	Sandstone, hard	2	668
White sand	18	204	Yellow clay	32	700
Sandy clay	10	214	Sand	10	710
Sand	12	226	Sandy clay	20	730
Red clay	26	252	Clay	20	750
Sand	38	290	Sand	25	775
Cemented sand, hard	4	294	Clay, hard	6	781
Red clay, hard	42	336	Yellow clay	19	800
Yellow clay	46	382	Sand	10	810
Sand	14	396	Sandy clay	30	840
Red clay, hard	32	428	Sand	30	870
Quicksand	18	446	Sandy clay	22	892
Cemented sand	6	452	Clay	8	900
Clay	4	456	Sandy clay	50	950

The following is a representative well record of the region northeast of Deming:

Record of well in the SW. ¼ sec. 30, T. 23 S., R. 7 W.

	Thickness.	Depth to base.		Thickness.	Depth to base.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Loam and clay	22	22	Sandrock	2	65
Gravel	2½	24½	Quicksand	1	66
Clay	4½	29	Gravel and sand, water bearing	6	72
Gravel with much water	5½	34½	Clay	3	75
Sand, tightly packed	5½	40	Gravel, coarse	1	76
Clay	10	50	Gravel, water bearing	3	79
Sand, tightly packed	5	55	Sandrock, soft	32	111
Clay	8	63			

In the Columbus region several borings penetrated basalt, evidently in thin sheets, included between sands and clays of the bolson deposits. Some features of the materials constituting the higher plain at the south end of the Tres Hermanas Mountains are exposed in deep railroad cuts east of Mimbres. The rise of the railroad grade here is 333 feet, but the only good exposures are in cuts through the upper deposits. These consist of soft pebbly sandstones and conglomerates in thick beds dipping 30° ENE. In the 200-foot rise at the western edge of the higher plain or plateau east of Arena the materials are more sandy, and in places there are soft sandstones, which are probably of Quaternary age but may be Tertiary.

CENOZOIC IGNEOUS ROCKS.[1]

CHARACTER AND AGE.

A great variety of younger igneous rocks are exposed in Luna County, comprising mainly porphyry of several varieties, an ex-

[1] The petrographic descriptions under this heading have been supplied by John L. Rich.

tensive series of latites, andesites, rhyolites and felsitic rhyolites, and basalt. The porphyry is in laccoliths and sills cutting strata as young as late Cretaceous and is believed to be of early Tertiary age. The latites, andesites, and rhyolites are mainly flows included in a great deposit of volcanic agglomerate and other fragmental material, regarded as of later Tertiary age, which underlies a large part of the region and rises in great prominence in the north end of the Florida Mountains and the ridges farther north. The order of succession of igneous flows in the agglomerate series is andesite, quartz latite, olivine-bearing andesite or quartz basalt, rhyolite and felsitic rhyolite. Keratophyre and quartz keratophyre occur in dikes and thin sheets, but their stratigraphic position is not clear, and there is also some doubt as to the relative position of the felsitic rhyolites. The basalt occurs as lava flows on Quaternary sediments and in dikes.

EARLY TERTIARY IGNEOUS ROCKS.

QUARTZ MONZONITE PORPHYRY AND SODIC GRANITE PORPHYRY.

Distribution.—Large masses of intrusive porphyry occur in Cooks Range west of the great fault, and Cooks Peak consists of that rock. A large irregular laccolith about 3 miles long constitutes the greater part of Fluorite Ridge. There are several dikes and sills offshooting from the larger masses, notably on the west slope of Cooks Range at Cooks post office and in Sarten Ridge. A small sill of similar rock is intruded in limestone south of Victorio Peak. Another small mass appears in a butte 3 miles east of Arena, and dikes of similar rock cut granite south of Capitol Dome. The porphyry cuts strata from Cambrian to later Cretaceous in age and probably also cuts the agglomerate or a part of it. It appears, however, to be older than any of the great flows in the agglomerate series. Therefore it is believed to be of early Tertiary age.

Character.—There is considerable variation in the character of the rock which ranges, with all gradations, from sodic granite porphyry to quartz monzonite porphyry and even to granodiorite porphyry. The porphyry in Fluorite Ridge and along the south side of the Cooks Peak mass has a dark-gray groundmass with white feldspar phenocrysts and abundant small hornblendes, while about Cooks Peak the groundmass is much lighter in color, the feldspar phenocrysts are larger, and the hornblende is much less abundant.

Petrography.—The sodic granite porphyry from Fluorite Ridge, which may be regarded as typical for the northern part of the area, is a porphyritic gray rock with phenocrysts of feldspar (mainly albite), hornblende, biotite, and quartz in a dark-gray felsitic groundmass. Hornblende and biotite in about equal proportions,

generally more or less altered to chlorite, occur in subordinate amounts. Quartz phenocrysts, many of them resorbed, are moderately abundant. The groundmass is essentially orthoclase and quartz with a little albite and augite.

The dikes and sills extending out from the larger masses present some variations from these features, either in a diminished amount of quartz, with increase in the proportion of hornblende, which occurs characteristically as long crystals, in places crossed or even as rosettes, or in a change to the more calcic feldspars—oligoclase and andesine—which mark the transition to typical quartz monzonite porphyry. The rock from the south slope of Fluorite Ridge is representative of these quartz monzonite porphyries. The phenocrysts are mainly andesine grading to albite in the outer zones, biotite, and quartz. The groundmass is a mosaic of quartz and orthoclase. The porphyry 1½ miles south of Cooks Peak contains more hornblende, a little more calcic feldspar, and less quartz in the groundmass than the rock just described and is typical quartz monzonite porphyry, as is also the rock near the fault 2 miles southeast of the peak.

The porphyry in the mass east of Arena is similar to the rock of Cooks Range but has larger phenocrysts of andesine.

Lindgren[1] has described the rock of Cooks Peak as a massive porphyry of gray color with prominent phenocrysts of andesine feldspar, many of which exhibit marked zonal structure. There are also a few crystals of hornblende and biotite; magnetite is relatively abundant, the groundmass is microcrystalline granular and consists essentially of the same minerals, together with quartz and orthoclase. The ferromagnesian minerals are partly altered to chlorite. Lindgren gives the following chemical analysis and norm:

Analysis of porphyry at Cooks Peak.

[By George Steiger.]

SiO_2	62.95	Na_2O	4.05	BaO	0.03
Al_2O_3	15.91	K_2O	2.95	SiO	.03
Fe_2O_3	3.30	H_2O	1.19		
FeO	1.37	TiO_2	.67		100.07
MgO	2.18	P_2O_5	.18		
CaO	4.46	MnO	.08		

Norm of porphyry of Cooks Peak.

[Calculated by B. S. Butler.]

Quartz	16.62	Diopside	3.89	Ilmenite	1.37
Orthoclase	17.79	Enstatite	3.60	Apatite	.34
Albite	34.06	Magnetite	2.55		
Anorthite	16.40	Hematite	1.60		98.22

[1] U. S. Geol. Survey Prof. Paper 68, p. 37, 1910.

In the quantitative system the rock is a dacose. By the ordinary classification it is best designated as a granodiorite porphyry, as it contains too much plagioclase to be termed a quartz monzonite.

GRANITE PORPHYRY.

Occurrence.—The peaks and higher portions of the Tres Hermanas Mountains consist of a porphyritic granite or granite porphyry which is intruded into limestones of later Carboniferous age. The mass is a large one, for the igneous rock exposed is 800 feet or more thick and occupies an elliptical area 5 miles long by 2½ miles wide. The rock cuts across and penetrates the limestone and includes huge masses of it. The sedimentary rock is metamorphosed into marble near the contacts, and various minerals are developed along them. The porphyry is a coarse-grained rock of massive structure and relatively uniform character throughout, except that the grain is slightly finer near the contacts with limestone. The rock is of light-gray color, but it weathers to a light-brownish tint, and the porphyritic character is brought out by weathering. A small mass of somewhat similar rock crops out in a butte 10 miles northeast of Arena, lying on agglomerate.

Petrography.—The rock of the Tres Hermanas Mountains has the composition of granite but differs considerably in aspect and composition from the pre-Cambrian granites of the Florida Mountains and the area to the north. Lindgren [1] calls it a coarse granite porphyry and gives the following description of a sample collected near the zinc mine:

> The rock is brownish gray and contains phenocrysts of orthoclase up to 15 millimeters in length, also small foils of biotite and small crystals of dark-green hornblende. Some oligoclase is associated with the orthoclase; the groundmass is micropegmatitic, consisting of quartz and orthoclase.

Of samples collected on the northern slopes of the mountains two were found to contain quartz in normal amount for a granite, orthoclase, the most abundant feldspar, with small amounts of oligoclase and albite, considerable biotite, and some hornblende. Another sample from the northeast corner of the Tres Hermanas area had abundant quartz and albite, considerable orthoclase and hornblende, and a small amount of biotite.

The rock in the butte northeast of the Birchfield ranch, in the southeastern corner of the county, contains abundant quartz and albite as the principal feldspar. Ferromagnesian (mafic) minerals are scarce.

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[1] Op. cit., p. 38.

LATER TERTIARY IGNEOUS ROCKS.

GENERAL RELATIONS.

The series of eruptive sheets interbedded at several horizons in the great succession of agglomerates and other fragmental rocks underlying much of Luna County comprises rocks of various kinds, mostly in widespread flows. These rocks crop out most extensively in the ridges extending along the east side of Cooks Range and constituting the southern extension of that range. The Little Florida Mountains contain a thick eruptive sheet; the Cedar Grove Mountains, Carrizalillo Hills, Fourmile Hills, and Taylor Mountain consist of a succession of flows and tuffs, and there are extensive flows in the Cow Spring Hills and on the flanks of the Tres Hermanas Mountains. Grandmother and Red Mountains and the high northern ridge of the Victorio Mountains consist of igneous rocks. Smaller areas appear in the Midway and Burdick hills, the hills north and east of Arena, and a number of low mounds rising out of the bolson. There are also many dikes and a few stocks, and doubtless extensive areas are hidden beneath the bolson deposits. In the great succession of flows and agglomerates, tuffs, and ash on the east side and south end of Cooks Range there is a wide area in which the sheets dip 5° to 40° NE., indicating a thickness of more than 2,000 feet, allowance being made for some duplication of outcrops by faulting. From two to six thick sheets of eruptive rocks are interbedded in the succession. Some of them are of great extent but others are small, so far as can be judged from outcrops. The largest flows in this area, which are near the middle of the series, consist of latite. The flows below the latite are andesite and those above are andesite, quartz basalt, and rhyolite. In the Little Florida Mountains the agglomerate includes a thick sheet of felsitic or vitreous rhyolite with local intrusions of keratophyre. The thick mass of agglomerate at the north end of the Florida Mountains consists largely of fragmental material with thin local sheets of keratophyre. The total thickness of the succession in the mountains appears to be between 1,700 and 1,800 feet in the great eastward-dipping mass which rises out of the bolson. The relations of these three large series of volcanic rocks to one another is not known, but the mass in the Little Florida Mountains appears to be stratigraphically higher than the mass in the Florida Mountains and probably represents at least a portion of the series appearing in Cooks Range. The agglomerates are described on pages 45–50. The wide area of agglomerate northeast of Cooks Range was not examined in detail and it contains several sheets of eruptive rock which are not shown on the map (Pl. I).

QUARTZ LATITE.

Relations and character.—The latite occurs mainly as flows, most of them thick and of great extent, interbedded at several horizons among the agglomerate and other pyroclastic deposits. Some of the masses are dikes in the agglomerate, doubtless feeders of surface flows. The largest outcrops are in the south end of Cooks Range and in the Cedar Grove Mountains. The rocks are compact but mostly coarse grained, of purplish-gray color, and of more or less porphyritic character, showing light-colored feldspar, dark hornblende, and in most specimens biotite. Some are dark gray and vesicular, others are of lighter color and include considerable tuff, and many of them are more or less deeply weathered. The rocks vary somewhat in mineral constitution, mainly in the amount of augite, which is lacking in some of the masses, and in quartz, which as a rule occurs in greater or less amount in the groundmass. Some of the latite resembles the andesites, but differs in containing a larger amount of potash feldspar, a distinction discernible only under the microscope; generally, however, the latites are much coarser grained and of lighter color. Varieties of the latite are difficult to separate in the field, and apparently they occur not only in separate flows but in different portions of the same mass.

Distribution.—The largest bodies of latite constitute the crest and part of the slopes of the Cedar Grove Mountains and of the south end of Cooks Range 5 miles west and southwest of Florida station. At the latter place there are two principal sheets separated by a varying thickness of agglomerate, ash, and other fragmental deposits, all dipping 10°–15° NE. Each of these sheets is probably made up of a succession of outflows. Another thick mass is interbedded in the agglomerate 4 miles northwest of Fort Cummings, probably at the same horizon as the others, and there is an extensive sheet in the Fourmile Hills and the slopes to the north. Smaller detached outcrops of latite appear in the Burdick Hills, in the slopes 3 miles southeast of Waterloo, and in a low knoll 2 miles east of the 76 ranch. Some of these may represent flows of considerable size, and possibly some may be dikes, but their structural relations are not exposed. In the outcrop 2 miles north of Mirage a dike of latite cuts the agglomerate.

In the ridges south of Fort Cummings and in a small outcrop west of Florida station the rhyolite is overlain by a thin sheet of brown latite containing augite, the highest horizon at which latite has been observed in this region. Augite-bearing latite predominates in the Cooks Range area, and latite with little or no augite constitutes the mass 3 miles northwest of Fort Cummings, a small intermediate flow 1 mile northeast of the Wilson ranch, a small mass 1½ miles

southwest of Fort Cummings, and some masses in the Burdick Hills and Cedar Grove Mountains and possibly in other places.

Petrography.—Most of the latite is pink to purplish in color, moderately compact, and porphyritic. Phenocrysts constitute about one-third of the rock. In order of abundance they are andesine-labradorite, brown hornblende, augite, and biotite in scattered large crystals. They lie in a felsitic groundmass, consisting mainly of minute laths of feldspar, much of which is orthoclase, and in many of the rocks there is also considerable quartz in the groundmass. The feldspar phenocrysts are commonly zonal and bordered by a rim of minute inclusions. In most exposures the ferric minerals, particularly hornblende and biotite, are considerably altered. In many of the masses augite is lacking, but in others it occurs in considerable amount. Pleochroic apatite is a characteristic accessory mineral. The quartz in the groundmass is as a rule difficult to distinguish. Determinations of silica in three specimens by Chase Palmer in the laboratory of the United States Geological Survey gave 64.75, 60.94, and 58.93 per cent, which indicate the presence of free silica. The first of these specimens was taken from the upper part of the large flow north of the Wilson ranch, the second from a thin flow 2½ miles southwest of Florida station, and the third from a fragment in agglomerate in the Goodsight Mountains.

One of the dikes cutting the agglomerate 2 miles northeast of Mirage siding contains augite. The extensive sheet on the northern slope of the Fourmile Hills is identical with some of the latite west of Florida station. It consists of phenocrysts of andesine-labradorite, brown hornblende, augite, and brown mica in a dense felsitic groundmass. The latite on the summit of the Cedar Grove Mountains at the Smith ranch and a sample from the west end of the range consist of phenocrysts of andesine and brown hornblende in a semi-vitreous purplish-brown quartz-bearing groundmass. The rock exposed 3 miles southwest of the 76 ranch contains augite. The latites in the Burdick Hills are nonaugitic. One of them is dark red to maroon in color, slightly besicular, and moderately porphyritic, with phenocrysts of hornblende and white or colorless feldspar. The rock in the large mass due west of Midway station is dense and rather poor in phenocrysts, particularly of the femic minerals. All have a dense matrix, apparently containing much orthoclase.

The rock of the sheet on the main road across the Cedar Grove Mountains, north of the Williams ranch, has abundant brown hornblende in a peculiar partly devitrified groundmass. Closely similar rock occurs in the sheet half a mile south of Hermanas station. The rock capping a foothill of the Tres Hermanas Mountains southeast of Waterloo is also a hornblende latite.

ANDESITE.

Character and occurrence.—The andesites differ from the latites just described principally in having a groundmass composed mainly of albite or oligoclase instead of orthoclase. Most of the andesites of this region appear to be richer in soda than normal andesites. It is difficult to distinguish some of the andesites from latite in the field, especially where the rocks are much weathered, but most of the andesites are much finer grained and darker colored than the latite. The andesites present considerable variation in the proportion of the dominant ferromagnesian minerals, hornblende, and augite. Most of them contain augite in abundance, but some have little or none. The andesites occur mostly in sheets interbedded in the agglomerate series, and although some of these sheets are higher in the succession than the latites and some lower, all belong to the same general period of effusion. A number of andesite dikes cut Paleozoic strata, granite, latite, and agglomerate. A sheet of andesite about 450 feet thick constitutes the high northern ridge of the Victorio Mountains. A thinner sheet lying on agglomerate, except near its west end, where a thin sheet of felsitic rhyolite intervenes, occurs below and above the latite sheet of the Cedar Grove Mountains, separated by more or less tuff. There are several thin sheets of andesite in the foothill ridges of Cooks Range 4 miles west and southwest of Florida station, at a horizon somewhat above that of the upper long sheet of latite. The lower one is about 80 feet thick and extends southeastward nearly to the railroad. The others are thinner and appear to lie in the midst of a thick body of volcanic ash and tuff. One thin sheet of latite occurs in this succession. Another sheet of andesite lies a short distance below the latite in the hills 4 miles northwest of Fort Cummings. It appears to be 200 to 300 feet thick and is flexed with the inclosing agglomerate. A small sheet or stock of similar andesite occurs a short distance below the base of the great latite sheet 3 miles northeast of Mirage siding. It gives rise to a small knob a few hundred yards west of the railroad and is inclosed in the agglomerate. A 20-foot dike of andesite traverses the latite of the main sheet on an east-west course a mile northwest of this locality, and other dikes of andesite with little or no augite appear in the agglomerate area 2 miles northeast of Mirage siding. One of these dikes or a sheet from it extends to the railroad and is exposed in a cut for 100 feet. Large dikes of andesite crop out in Massacre Peak, in the small ridge half a mile to the west, and in the prominent ridge just north of Puma Spring. These dikes cut the agglomerate, and the mass in Massacre Peak is a stock. The dikes in the ridge next west and in the ridge on the south trend northwest, or at right angles

to the large masses. A dike of very mafic character cuts the granite 2½ miles northeast of China Tank. Other dikes cut the granite just south of Capitol Dome, in the Florida Mountains. A thin sheet of andesite occurs in the agglomerate at Capitol Dome and another caps the small knob of agglomerate in the faulted block a mile southeast of Arco del Diablo. A small outcrop in the slope west of the Little Florida Mountains is apparently overlain by rhyolite. These rocks in the Florida and Little Florida mountains show little or no augite. A small hill of andesite lies near monument 14 of the Mexican boundary and a thin sheet appears in the tuff and agglomerate a short distance below the main latite sheet on the west slope of the Fourmile Hills. Fragments of andesite occur in the agglomerate of the Florida Mountains, in Red Mountains, and in Cooks Range.

Petrography.—The andesites are characterized by medium dark color inclining toward purple tones. All are fine grained and compact and none are vesicular. Fluidal texture is common. Phenocrysts of feldspar (oligoclase-andesine to labradorite), brown hornblende, augite, and rarely biotite are embodied in a finely crystalline groundmass rich in albite. Chlorite and calcite are common secondary products, and magnetite, titanite, and apatite are the usual accessory minerals.

The andesite sheet in the Victorio Mountains is a massive purplish-gray rock with feldspar, hornblende, and biotite phenocrysts in a dense groundmass.

The sheet of andesite on the south side of the Cedar Grove Mountains is closely similar to the sheet above the latite near the Smith ranch, on the opposite side of the mountains, and also to the intrusive mass of Massacre Peak. The lower sheet of andesite 4 miles southwest of Florida station differs from all the other andesites in containing numerous phenocrysts of unaltered green hornblende instead of the usual brown hornblende. It has little or no augite. The next higher flow, a thin one, is an andesite of the normal type, with brown hornblende and abundant augite. The next sheet contains but little augite and approaches keratophyre, while the uppermost sheet, which lies above considerable agglomerate, is a hornblende andesite bordering on latite.

The andesite occurring in dikes shows no special characteristics but is finer grained and darker colored than that of the sheets.

QUARTZ BASALT.

Distribution and character.—In the region south and southwest of Fort Cummings the igneous sheet next above the latite consists of a dark-colored, moderately coarse-looking, distinctly porphyritic rock, with white phenocrysts of striated feldspar embedded in a

purplish-gray aphanitic groundmass. In composition it ranges from quartz basalt to olivine-bearing andesite, but all of it is of the same general appearance and very unlike the igneous rocks above and beneath it. Parts of the rock now contain no olivine, but apparently its absence is due to alteration, as in some specimens there are outlines of an altered mineral which appears to indicate its former presence. The largest exposures are in the center and east slope of the large dome-shaped uplift half a mile south of Fort Cummings, where it has been bared by the removal of the overlying rhyolite and ash. It is also exposed along the bases of the ridges 2 and 3 miles south of the fort, where the outcrop is repeated by faulting, and remnants of a widespread sheet cap some of the ridges on both sides of the main road east and north of Massacre Peak. An interrupted outcrop zone also extends along the slopes south and southeast of that peak on the west slope of the structural dome. The southwesternmost exposure is a quarter of a mile northwest of Puma Spring. The sheet is at least 200 feet thick in the dome south of Fort Cummings, but it is thinner to the west and is probably discontinuous in places along the western margin of its outcrop. In the center of the dome south of the fort the lowest rock appears to be coarser grained than the main body above. The latter is overlain by a series consisting of tuff, agglomerate, and ash containing a thin sheet of andesite, which extends to the base of the thick rhyolite sheet capping the main ridge. This relation is general throughout the area south and southwest of the fort, but the intervening body of pyroclastic rocks ranges from 40 to 150 feet in thickness. Below the sheet of quartz basalt, between it and the top of the main latite body, there is also some agglomerate. This relation is well exposed in the outcrop 2 miles west of the fort, where 40 feet of ash intervenes between the two sheets.

Petrography.—The quartz basalts show moderately abundant phenocrysts of feldspar (andesine-labradorite), biotite, hornblende (represented in most specimens only by characteristic outlines filled with secondary alteration products), and olivine (also generally altered, either to iddingsite or to serpentine). These minerals lie in an aphanitic groundmass composed of small plagioclase laths, augite rods, and magnetite specks in a matrix of poorly crystallized feldspar, some of it apparently orthoclase. The rocks from different outcrops vary somewhat in the proportions of olivine and orthoclase, and therefore range in composition from olivine-bearing latites to basalts.

Quartz in xenocrysts as much as 1.1 millimeters in diameter is a common constituent. The quartz crystals are bordered by reaction rims of augite, and most of them show resorption.

KERATOPHYRE.

Distribution and relations.—Keratophyre, some of it grading to quartz keratophyre, occurs in sheets and dikes at a number of places in Luna County. The largest mass is one which partly encircles the Tres Hermanas Mountains, where it separates the porphyry and felsitic rhyolite. A small sheet caps agglomerate just east of the Cedar Grove ranch. A small outcrop of keratophyre extends for a short distance along the foot of the west slope of the Little Florida Mountains, as shown in section B, figure 7 (p. 78). Its relations are not well exposed, but it appears to cut or be faulted against the obsidian and tuff deposits that underlie the main sheet of felsitic rhyolite. A wide dike of the same rock cuts the rhyolite, obsidian, and tuff succession at the southeast corner of the same range. The rocks here consist mostly of thin, nearly vertical plates of reddish color. Thin sheets of keratophyre or of tuff of nearly the same material are interbedded in the lower members of the pyroclastic series near Capitol Dome. A large vertical northeast-southwest dike of keratophyre 20 to 30 feet wide in places and nearly a mile long cuts the agglomerate 4 miles northwest of China Tank and crops out as a long, narrow ridge. It has two short branches near its middle. A similar dike with nearly the same thickness and trend crosses the bolson slope 1½ miles farther south. A small dike cuts the El Paso limestone half a mile north of Capitol Dome, and other similar dikes are in the granite west and south of the dome. A short distance south of Arco del Diablo a large dike of keratophyre extends from the bottom of the mountain nearly to the top. It ranges in width from 15 to 25 feet in greater part and cuts the granite for 1,000 feet or more. As it is softer than the granite, its course is marked by a deep ravine up the slope, in parts of which the relations are clearly exposed. Along the contact on each side much epidote is developed in nodules arranged parallel to the granite. The keratophyre of the Tres Hermanas Mountains appears to be a sheet surrounding the porphyry and in part uplifted in the general dome-shaped uplift of the area. Apparently it underlies the felsitic rhyolite, which has flowed over the irregular surface of the keratophyre, but it may be a later intrusion.

Character.—The keratophyre is a fine-grained dark-gray, highly sodic rock, with little or no quartz and with subordinate mafic minerals. Some masses have a lighter greenish tinge due to grains of epidote. Most of the rocks are apparently intermediate between andesites and the felsitic rhyolites and quartz keratophyres. Their texture is generally felsitic, but they show a tendency toward the development of small phenocrysts of feldspars less than 0.5 millimeter long.

Petrography.—The microscope reveals a well-developed porphyritic fabric. Small phenocrysts of feldspar ranging from albite to oligoclase lie in a microfelsitic groundmass apparently made up largely of albite. Calcite and epidote have replaced any mafic minerals which may have been present. The keratophyre of the Tres Hermanas Mountains does not differ essentially from the type. The rock of the sheet on the side of the Cedar Grove Mountains is a little more basic than the others but is closely related.

The dikes of quartz keratophyre traversing the granite west of Capitol Dome have orthoclase phenocrysts as much as 5 millimeters long, rather sparsely distributed in a microgranular groundmass of quartz and albite with a little magnetite. The phenocrysts are of local development, for some of the rock contains none.

RHYOLITE.

Distribution and relations.—Rhyolite occurs at many places in Luna County, but the largest masses are parts of a widely extended sheet or succession of sheets lying not far above the quartz basalt west and south of Fort Cummings. Originally this sheet probably extended over a wider area toward the west and it has been removed from the wide dome about Massacre Peak. The easterly dip carries it beneath the bolson southeast of the fort, and it may extend underground in that direction for some distance. A large area of similar rock forms the southeastern slope of the Cow Spring Hills, and it also occurs in the west end of the Klondike Hills and the eastern and southern parts of the Carrizalillo Hills. A thin sheet lies on the agglomerate on the west slope of the Cedar Grove Mountains north to the Williams ranch and also in the slopes east of Cow Spring. The large area northeast of the Grandmother Mountains consists of three sheets 120 feet thick lying on 150 feet of ash and fine tuff, apparently in a block uplifted above the felsitic rhyolite to the north. The upper sheet is light colored, the lower one brownish, both are massive and each is about 60 feet thick. A thin bed of darker rock separates these sheets. All the rocks appear to be closely similar in mineralogic character. A dike of similar rock appears on the west side of the Little Florida Mountains and there is a small outcrop of it near the north end of that range. Other small exposures are found in the Burdick Hills and in a small knoll 4 miles west of Black Mountain. A small sheet caps the hill of agglomerate east of Fluorite Camp, and another mass rises out of the bolson in a low knoll half a mile southeast of the camp. A small outlier rises into a prominent knob half a mile northeast of Massacre Peak. It dips east and owes its presence here to a fault. The extensive sheet south and west of Fort Cummings is about 100 feet thick and lies on volcanic ash and tuff 20 to 150 feet thick, which separates it from

the underlying quartz basalt. In most places it consists of two flows, the lower one light colored and coarse grained, the upper one pinkish and fine grained. At one place on the ridge 1½ miles south of the fort these flows are separated by a local bed of volcanic ash 15 feet thick. In part of this area also there is another sheet 30 feet thick 100 feet below. No overlying beds are exposed except near Fort Cummings, where the much younger basalt appears.

Character.—The rhyolite presents some diversity in appearance though but little in composition. In texture it ranges from compact semivitreous to dense porphyritic rock with prominent phenocrysts of quartz, feldspar, and mica. In color it ranges from white in the more vesicular varieties through varying shades of gray and pink, the latter locally inclining to purple tones. Its mineral composition is uniform. It consists of a glassy, axiolitic, partly devitrified groundmass, in which are phenocrysts of quartz, sanidine, plagioclase, biotite, and usually brown hornblende. Biotite is present in all specimens, but the hornblende is moderately abundant in some places and absent in others.

Petrography.—The dense porphyritic rock of the large sheet 1½ miles southwest of Fort Cummings is representative of the rhyolite as a whole. It is pinkish and shows small phenocrysts of quartz, feldspar, hornblende, and biotite in a pink felsitic groundmass. The biotite flakes are mostly of characteristic coppery-brown color. Quartz phenocrysts are abundant. They are commonly corroded and many of them have been fractured subsequent to the corrosion, probably as a result of flow movement in the cooling lava.

The feldspars consist of sanidine and plagioclase in about equal proportions. The plagioclase differs somewhat in composition, but in general, as indicated by the index of refraction, it corresponds with sodic andesine, approaching oligoclase. The feldspar phenocrysts, like those of quartz, are both resorbed and fractured, the plagioclase in particular showing marked corrosion. Hornblende is conspicuous, though nowhere so abundant as biotite. The groundmass is notably axiolitic and contains considerable glass. Accessory minerals are titanite, in crystals nearly 0.5 millimeter in length, and magnetite. The ratio of groundmass to phenocrysts averages about 3 to 1.

Other specimens of rhyolite differ from the typical rock above described in several respects. In color they range from white through varying shades of gray and pink, and in texture from moderately vesicular to compact, almost glassy. In some places the rock contains abundant fragments of pumice. In mineral composition there is variation in the proportions of the feldspar phenocrysts, plagioclase being slightly in excess in some of the rocks and sanidine in others. The hornblende also varies in proportion, and in some of the masses

it is absent. The proportion of glass in the groundmass varies, and a black obsidian from the west base of the Little Florida Mountains is almost wholly glass.

FELSITIC RHYOLITE.

Distribution.—Felsitic rhyolite, or dacite, of slightly varying composition crops out extensively in different parts of Luna County. Some occurs in the form of irregular masses, as in the Grandmother Mountains, Red Mountain, Gray Butte, Cow Cone, and the White Hills, probably representing the stocks of old volcanoes, and in the Little Florida Mountains, on the flanks of the Tres Hermanas Mountains, in the Cow Spring Hills, and on Taylor Mountain there are sheets of similar rock. Small masses of unknown structure rise out of the bolson in the Midway Buttes south of Iola, northeast of Spalding, 3 miles south of the Victorio Mountains, in slopes west of the Little Florida Mountains, on the Grant-Luna county line, 5 miles north of Cow Cone, and in hills 2 miles southeast of Arena. Another small mass, apparently intrusive, separates rhyolite from latite in a hill 6 miles west of Iola. A long dike crosses the Florida Mountains south of Arco del Diablo, cutting agglomerate, the Lobo formation, and granite.

Relations.—In the Tres Hermanas Mountains and in the small butte 3 miles east of Cow Spring the felsitic rhyolite is overlain by basalt, and in the former place it overlies keratophyre. These are the only evidences of its relation to other igneous rocks. The sheet in the Little Florida Mountains appears to be younger than a dike of hornblende-biotite rhyolite that cuts sediments on the west slope of the mountains, but the evidence of this is not conclusive. In the Gray Butte region the felsitic rhyolite appears to overlie the other rhyolite, but there may be a fault between them. In the ridge 4 miles northwest of Gray Butte hornblende-biotite rhyolite occurs higher on the slope than the felsitic rhyolite, but the relations of the two masses are not clear.

Character.—The felsitic rhyolite is fine grained and mostly white, though in places it is brownish red, gray, or light purplish gray. It varies from a rock near normal rhyolite in one direction toward quartz keratophyre or toward dacite in others, but the differences can not be recognized in the field; and on account of the small size of the crystals it is difficult to determine the varieties with certainty under the microscope. There is probably a gradation through all stages from rocks high in potash to those high in soda.

A characteristic of the felsitic rhyolite is its micrographic texture. Spherulitic fabric also is perfectly developed in some of the rocks. A chalky appearance and texture is a further peculiarity of most of them. Part of the larger sheet in the Little Florida Mountains is

vitreous, in places containing some fragmental material in its lower part and near the center of the mountains showing much silicification. Much of it is pale brownish pink.

Petrography.—The typical felsitic rhyolite in Red Mountain and the White Hills is almost pure white, of perfectly uniform felsitic texture, and almost entirely free from phenocrysts. The microscope shows orthoclase and abundant quartz in micropegmatitic intergrowth. Spherulites, mainly of feldspar, are recognizable, but are not so prominent as in many of the other masses. Femic minerals are represented only by scattered specks of iron oxide, mostly hematite, and a very little biotite. Zircon is a moderately abundant accessory. The rock from the small masses east of Arena is closely similar, but has scattered phenocrysts of biotite and oligoclase. The rock on the northwest slope of Taylor Mountain is a white, fine-grained rock with a few phenocrysts of oligoclase-andesine, a little brown hornblende, and a subordinate amount of interstitial quartz. The rock of Cow Cone is nearly white and fine grained, and consists of very small phenocrysts of oligoclase-andesine, and a few flakes of biotite in a micrographic groundmass rich in albite and containing a very little quartz. The rock in massive ledges at the north end of the Cow Spring Hills, half a mile southeast of Cow Spring, has a minute granular texture with irregular intergrowth of quartz and albite, the latter in excess. The rock from the Grandmother Mountains has a granophyric texture with no well-marked phenocrysts. Interstitial quartz is moderately abundant. The feldspars appear more calcic than in most of the other rocks of the group. The felsitic rhyolite in the northeastern foothills of the Tres Hermanas Mountains is very similar to that of Red Mountain, except that it shows no quartz. The lower sheet of igneous rock in the southwest end of the Victorio Mountains is a dark-gray felsitic rhyolite or dacite. A 10-foot sheet of somewhat similar rock of white color is interbedded on the north side of the ridge near its northwest end. In the massive rock at the base of the main flow at the middle of the west side of the Little Florida Mountains the rhyolite is vitreous, reddish brown, and somewhat banded in structure. It contains much quartz, which is due to silicification. The orthoclase is radial, and there is some blue amphibole. Some of the rock at the north end of the mountains is similar and also includes fragmental matter.

RHYOLITE PORPHYRY.

Dikes of rhyolite porphyry, doubtless closely related genetically to the rhyolites, traverse the granite west of Arco del Diablo and 2 miles south of Gym Peak and form a small group of knolls 4 miles

southwest of Iola. All are closely similar, do not differ greatly from the felsitic rhyolite in appearance, and range in color from almost pure white to light pink. They have a microgranular groundmass of quartz and orthoclase, through which are scattered small phenocrysts of quartz, sanidine, and albite, abundant in the order stated.

QUARTZ DIORITE.

A body of quartz diorite crops out in a small area at the Hancock mine, in the foothills on the west side of the Tres Hermanas Mountains. Apparently it underlies the rhyolite. The rock is unlike any others found in the county, but resembles some which occur near Silver City. It consists of green hornblende, biotite, augite, and feldspar, mainly labradorite. The quartz is interstitial and not specially abundant.

QUATERNARY IGNEOUS ROCKS.

BASALT.

Distribution and relations.—The youngest volcanic rocks in Luna County are flows and dikes of basalt. These flows lie on and perhaps are also interbedded with the Quaternary bolson gravels, which belong to the latest epoch in the geologic history of the region. A thick sheet of the basalt caps tuff and other fragmental deposits in Black Mountain and sinks beneath the bolson at its east end. A smaller mass, possibly connected underground, rises out of the bolson 2 miles to the northwest. Large sheets of basalt cap the Goodsight Mountains and the northeastern ridge of the Cedar Grove Mountains. They lie on sand, tuff, and ash deposits. An irregular flow underlies the area about Fort Cummings and rises in low ridges to the east and west of the fort. Part of this material near the fort is very spongy with gas cavities, and some of it is an agglomerate or mud flow. Flows of moderate extent appear along the El Paso & Southwestern Railroad between Mimbres and Hermanas and lie on the south slope of the Cedar Grove Mountains at the Williams ranch. Two masses rise out of the bolson southeast of Tomerlin; small areas constitute low buttes just south of Columbus, in the gap at the south end of the Florida Mountains, and both sides of the valley east of Cow Spring. A thin sheet of basalt caps the buttes on the northeast end of the Tres Hermanas Mountains and the butte known as Black Top, on the west side of that range, in both places lying on rhyolite. A small mass, probably a flow, crops out in the valley 6 miles southwest of Iola. Long, narrow dikes of basalt cut porphyry and sandstones in Fluorite Ridge, and a small dike of it cuts across the southwest end of Black Mountain. Other dikes cut limestones and associated rocks

5 miles northwest of Fryingpan Spring and at Cooks post office. Two dikes, 20 feet wide, with branches cut tuff 1¼ miles south of Massacre Peak, and others cut granite south of Capitol Dome.

The basalt of these localities is a fine-grained black rock of exceptional hardness. Some of the rock of the flows contains many gas cavities, but the dike rock is dense and more coarsely crystalline.

Petrography.—The basalt in the flows is nearly uniform in appearance. The commonest sort, such as that of Black Mountain, contains phenocrysts of feldspar and olivine, the latter generally clear in the center but changed to iddingsite around the borders. The groundmass is made up of laths of labradorite, between which are packed small anhedrons of augite, olivine, and magnetite.

The basalt of the other flows differs from that above described only in minor particulars. The flow at Fort Cummings is in part highly vesicular, and the cavities are filled with thomsonite and heulandite. In the knoll 3 miles east of Cow Spring the basalt is very fine grained, black, and full of cracks and flow lines which are well brought out by weathering. It is a sheet 40 feet thick and lies on tuff and felsitic rhyolite. The basalt capping the low ridge 2½ miles farther east is a coarser-grained rock of peculiar brown color, due to deep weathering. The basalt of the eastern ridge of the Cedar Grove Mountains is fine grained, and the olivines are not very abundant. The basalt in the small area 5 miles southwest of Iola is probably an extension of the same flow.

Certain notable features appear in the basalt sheet capping the Goodsight Mountains. It is coarser in crystallization than most of the other flows, or more like the dike forms. It shows peculiar rims of clear olivine around cores of the red variety, except where the olivine is entirely surrounded by the feldspars or where the olivine crystals adjoin phenocrysts of feldspar; in other words, the rim is not developed between olivine and feldspar. This relation suggests two periods of growth of the olivine—one producing the iddingsite prior to the crystallization of the feldspar phenocrysts, the other and later doubtless corresponding in time with the crystallization of the augite and feldspar of the groundmass.

The basalt of the dikes is coarser and more uniform in texture than that of the flows, though evidently of about the same composition. The dike cutting the agglomerate at the west end of Black Mountain is typical. It is holocrystalline and almost black. Laths of feldspar as much as 2 millimeters long and irregularly shaped olivines 1 millimeter or less in diameter lie in a matrix of feldspar, olivine, augite, and magnetite. Being comparatively fresh, this rock exhibits the beginning of an alteration of the olivine to felted green and brown aggregates of talc and biotite. In the other dike basalts

this alteration has progressed so far that it partly obscures the original nature of the rock.

The dikes of Fluorite Ridge, south of Capitol Dome, near Cooks post office, and 5 miles northwest of Fryingpan Spring are closely similar in character, but the rock from Fluorite Ridge is more altered. The dikes in granite south of Capitol Dome contain much magnetite in specks through the augites and even in the feldspars.

STRUCTURAL GEOLOGY.

GENERAL FEATURES.

Owing to the fact that the rocks exhibiting structure are in isolated ridges and hills widely separated by bolsons, it is not possible to determine the general structure in Luna County. There are no visible features which indicate extensive monoclines, synclines, or anticlines. The relations in the Florida Mountains suggests the east limb of an anticline, but the western limb of the flexure is not apparent. Cooks Range is in part an anticline rising to the north and pitching down into a broad syncline at the south end. A great fault extends along the east side of the main Cooks Range with a drop of several thousand feet in its east side, but no other longitudinal faults of any great displacement were observed. Possibly the lowlands now occupied by the bolsons are down-faulted blocks, but there is no evidence of it. On account of these conditions no general cross sections of the region are presented in this report, and the structure of each ridge or outcrop area will be described separately. In general, it is suggested that the bolson depressions are due chiefly to erosion of the softer rocks of the later formations, notably the soft shale and sandstone of later Cretaceous and early Tertiary ages, but no direct evidence on this matter is available.

COOKS RANGE.

SUBDIVISIONS.

Cooks Range is divided into two very distinct geologic districts by the great fault which passes along the east side of the range and crosses it southwest of Fort Cummings. To the west are Paleozoic and Mesozoic limestones and sandstones, penetrated by a great laccolithic mass of porphyry; to the east is the agglomerate series with its included sheets of igneous rocks. Accordingly these two portions will be described separately in the following pages.

MOUNTAINS AND RIDGES WEST OF THE GREAT FAULT.

The dominant feature of the main Cooks Range and of Cooks Peak, its culminating summit, is a large laccolithic mass of granodiorite porphyry. This rock has been intruded mainly in the Lake Valley

limestone, but locally it rises across the strata up to the Sarten sandstone and Colorado shale. The sedimentary rocks have in general a steep dip away from the central igneous mass, and there is some faulting along the flanks of the uplift. Several separate intrusions of large masses of porphyry rise in ridges to the southwest and south of the central area, but these are much more irregular in their structural relations than the laccolith of Cooks Peak. The salient features of the main Cooks Range are shown in the sections of figure 3 (p. 70).

Numerous small dikes and sheets are intruded at various places, notably about Cooks post office, where there are several dikes of basalt and porphyry. On the west slope of the range the limestones are cut at several localities by irregular projections from the main porphyry mass. North of the Cooks Peak igneous mass there is a shallow syncline which crosses the range near Cooks post office. On the north side of this flexure there are low dips to the south and the strata rise in successions in a long ridge that narrows toward the north. The formations exposed are the Lake Valley limestone, Percha shale, Fusselman limestone, Montoya limestone, El Paso limestone, Bliss sandstone, and granite. The granite extends for some distance north out of the county. East of this ridge there is a profound fault which crosses the high ridges north of Cooks post office and extends far south along the east side of the Cooks Peak mass and Sarten Ridge. Between this fault and Cooks Peak there is a shallow syncline which holds beds up to the Sarten sandstone, the sandstone occurring mainly in small outliers lying high against the east slope of the mountain. Other similar outliers cap peaks north and northwest of Cooks Peak. The Sarten sandstone appears at intervals on the lower part of the west slope northwest of the peak, and it is probably continuous under the bolson deposits to the 55 ranch, where it lies in a syncline that extends southeastward far up into the ridge between the two masses of porphyry. At one place this syncline holds a small area of the Colorado shale. Farther south the Lobo formation, Gym limestone, and Lake Valley limestone rise to the surface and these formations together with the Sarten sandstone constitute the high ridge extending across the range 2 miles south of Cooks Peak. The strata in this ridge all dip south at moderate angles, as shown in section 4 of figure 3, and are cut off by the great fault to the east. The Sarten sandstone is a conspicuous feature in this area, constituting the very prominent dip slope 2 miles south of the peak which on the east swings around to the south and becomes Sarten Ridge. It also extends several miles to the southwest, so that with Sarten Ridge on the other side it finally forms the rim of a wide syncline. The north side of this syncline is cut by an irregular mass of

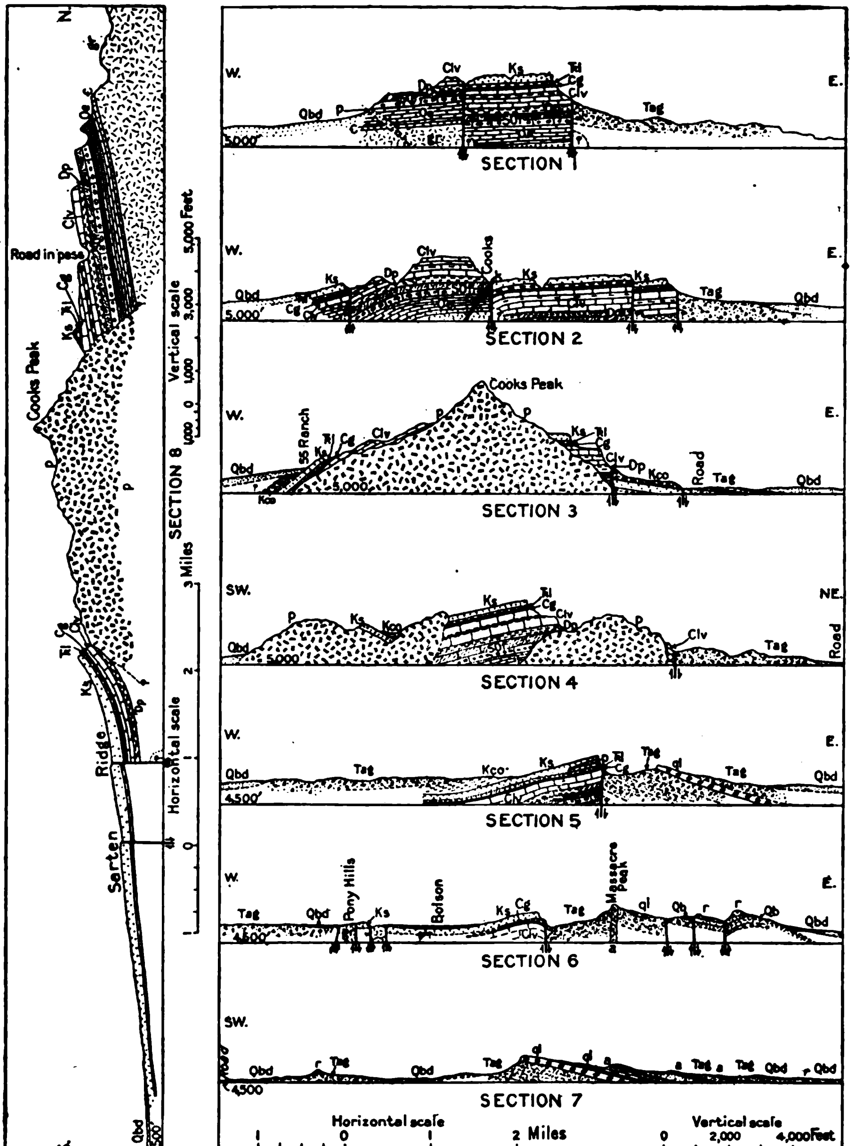

FIGURE 3.—Sections across Cooks Range. 1, 1½ miles north of Cooks post office; 2, through Cooks post office; 3, through Cooks Peak; 4, 2 to 3 miles south of Cooks Peak; 5, 1½ miles north of Fort Cummings; 6, 1½ miles south of Fort Cummings, passing just south of sandstone quarry; 7, from point 1½ miles southeast of Fluorite Camp to point 1½ miles northwest of Florida station; 8, through Cooks Range from southeast end of Sarten Ridge to the Luna-Sierra county line. Base of sections 1–4, 5,000 feet above sea level; 6–8, 4,500 feet. p, Porphyry; Tag, agglomerate; r, rhyolite, andesite, and latite; Qbd, bolson deposits; Kco, Colorado shale; Ks, Sarten sandstone; Tl, Lobo formation; Cg, Gym limestone and Magdalena formation; Clv, Lake Valley limestone; Dp, Percha shale; SOf, Fusselman and Montoya limestones; Oe, El Paso limestone; Є, Bliss sandstone; gr, granite; a, andesite; Qb, quartz basalt; ql, quartz latite; k, keratophyre.

porphyry high on the mountain slope, but lower down there is a small area of the Colorado shale and large areas of agglomerate and associated deposits.

In Sarten Ridge the sandstone is underlain by the Lobo formation and the Gym and Lake Valley limestones, which crop out along the north and east slopes of that ridge until they are finally cut off by the great fault north of Fryingpan Spring. A small amount of the Percha shale also appears in this area, cut by the porphyry of the main Cooks Peak laccolith. There is a large intruded mass of the porphyry on the south slope of the high sandstone ridge, and some small dikes and sills of it to the east in Sarten Ridge. At two places the sandstone is exposed overlain by the Colorado shale, and doubtless this formation underlies an area of considerable extent in the syncline west of Sarten Ridge, but it is mostly covered by agglomerate and later deposits.

Sarten Ridge consists of a wide exposure of the Sarten sandstone dipping south of west and finally passing beneath bolson deposits at the south end of the ridge. The great fault passes along the foot of the east side of the ridge, and owing to this dislocation the agglomerate abuts against the Sarten sandstone to the south and then against the Lobo formation and Lake Valley limestone as these formations rise to the north. At Fryingpan Spring the Sarten sandstone with a nearly north strike and a very low dip to the west abuts against the agglomerate series, which strikes northwest and dips at angles mostly greater than 20°. The vertical displacement caused by the fault at this place is probably more than 1,000 feet, but there is no way of determining the precise amount. Half a mile south of Fryingpan Spring a deep canyon in Sarten Ridge cuts through the sandstone and reveals the underlying Lobo formation in a small area. A few rods to the southeast a small mass of limestone appears along the fault, probably a wedge that was slightly more uplifted than the Sarten Ridge block. It appears to be the Gym limestone, but no fossils were obtained on which to base precise correlation. The beds are nearly horizontal and lie on conglomerate, of which the top crops out a few yards east of the road.

AGGLOMERATE AND IGNEOUS AREA EAST OF THE GREAT FAULT.

The southern extension of Cooks Range east of Sarten Ridge consists of the great agglomerate series with its included igneous masses, the latter mostly in sheets. There is an alternation of strata and interbedded lava flows, in part in regular succession from southwest to northeast, for the dip is generally to the east and northeast at a moderate angle. Several faults break the succession locally, and it is all cut off diagonally on the west side by the great fault that ex-

tends along the east foot of Sarten Ridge. To the east it passes beneath the bolson deposits, and these also form an irregular margin along its southern and southwestern portions. About Fort Cummings some later basalts lie on the margin of the series. The lower members of the agglomerate series exposed constitute a thick succession of deposits of fragmental volcanic materials with a few small dikes of various rocks. Interbedded brown quartzites constituting the two prominent knobs 3 miles west of Mirage are exceptional features, for apparently they do not contain igneous material. Several strata of sedimentary origin are interbedded with the agglomerate, and all dip nearly due east at an angle of 4°. In the steep, high ridges east of the Wilson ranch the first great sheet of latite appears lying in the agglomerates, both dipping 10° NE. Above this thick sheet there is a thick succession of flows and local deposits of agglomerate, tuff, and ash, all dipping at low angles to the northeast. North of the Wilson ranch, however, an anticline or dome is indicated by westerly and southwesterly dips, mainly in an area limited on the east by a crescentic fault which cuts off the beds in an irregular manner. The deposits of sedimentary and fragmental rocks thicken and thin from place to place, and thin flows of andesite are included which thicken to the east and south. A widespread sheet of quartz basalt, apparently merging into olivine andesite, is a prominent member of the series west of Florida, and not far above it is an extensive sheet of light-colored rhyolite in the ridges south of Fort Cummings. The two sheets of igneous rock are separated by deposits of volcanic ash, which in most places are 100 feet thick. Two faults cut the rocks in this portion of the area, repeating the succession of rocks from quartz basalt to rhyolite along two zones of outcrop. The individual relations of these faults are shown in section 6 on figure 3 (p. 70).

Northwest of Fort Cummings the igneous rocks are in thick masses in the agglomerate and appear to terminate by thinning out. Here the members of the series generally dip to the east and northeast at various angles, but there are southeast dips on the curved outcrops 3 miles northwest of the fort. To the west this body of igneous rocks is cut off diagonally by the great fault, and to the east it disappears beneath bolson deposits.

South of Fort Cummings the rhyolite and underlying rocks exhibit an oval dome with axis trending southeast. The upper rhyolite has been removed from the top of the dome, revealing the quartz basalt, which on the southeast side extends down to the bolson.

In the area about Puma Spring and for several miles to the north there is a low dome lying between the faults. One of the most notable effects of the uplift is the presence of a sheet of the rhyolite in the high ridge west of the spring. This sheet appears to be at the

same horizon as the other bodies of rhyolite to the northeast. It dips southwestward and lies on a thick body of volcanic ash, which in turn is underlain by quartz basalt. Next east is a thick dikelike mass of andesite which extends to Puma Spring. Farther north, toward Massacre Peak and the main road, the dome is nearly flat and the sheets of rock dip northward. At the fault half a mile northeast of Massacre Peak the rocks dip steeply to the east, notably the wedge of rhyolite forming the 5,050-foot peak, which dips 25° ENE.

FLORIDA MOUNTAINS.

GENERAL STRUCTURE.

The Florida Mountains consist mainly of pre-Cambrian granite and agglomerate, the latter constituting the high, rugged ridge at the north end of the range. Paleozoic limestones also occur in several areas, one mass forming the crest of the mountains for a short distance east of The Park. In general the range has a monoclinal structure with an easterly dip. Possibly it is the eastern limb of an anticline whose axis lies under the bolson on the west, or the uplift may be bounded on that side by a fault. At Capitol Dome the Paleozoic rocks and agglomerate beds all dip to the east-northeast, and the granite crops out along the foot of the western slope. This easterly dip, with repetition of the limestones by faulting, is exhibited again farther south, at The Park and Gym Peak. The range is crossed near its north end by a profound fault that trends nearly east and has an upthrow of several hundred feet on its south side, and the limestones of The Park and Gym Peak are cut off to the south by a great fault which uplifts the granite more than 2,000 feet. The salient structural features of the range are shown in the sections of figure 4 (p. 74).

FLEXURES.

The rocks of the Florida Mountains are tilted in various directions in extensive monoclines, but they are not flexed into anticlines or synclines to any great extent. The agglomerate dips gently to the east and east-northeast, and the underlying Lobo formation has essentially, if not precisely, the same attitude. The Paleozoic rocks also, with a few exceptions, dip eastward. At Gym Peak, as shown in section C, figure 4, there is slight arching, and the faulted blocks to the west include some shallow synclines.

FAULTS.

Faults are numerous in the Florida Mountains, and the larger ones cross the range from east to west. The largest, which passes along the south side of The Park and a short distance south of Gym Peak,

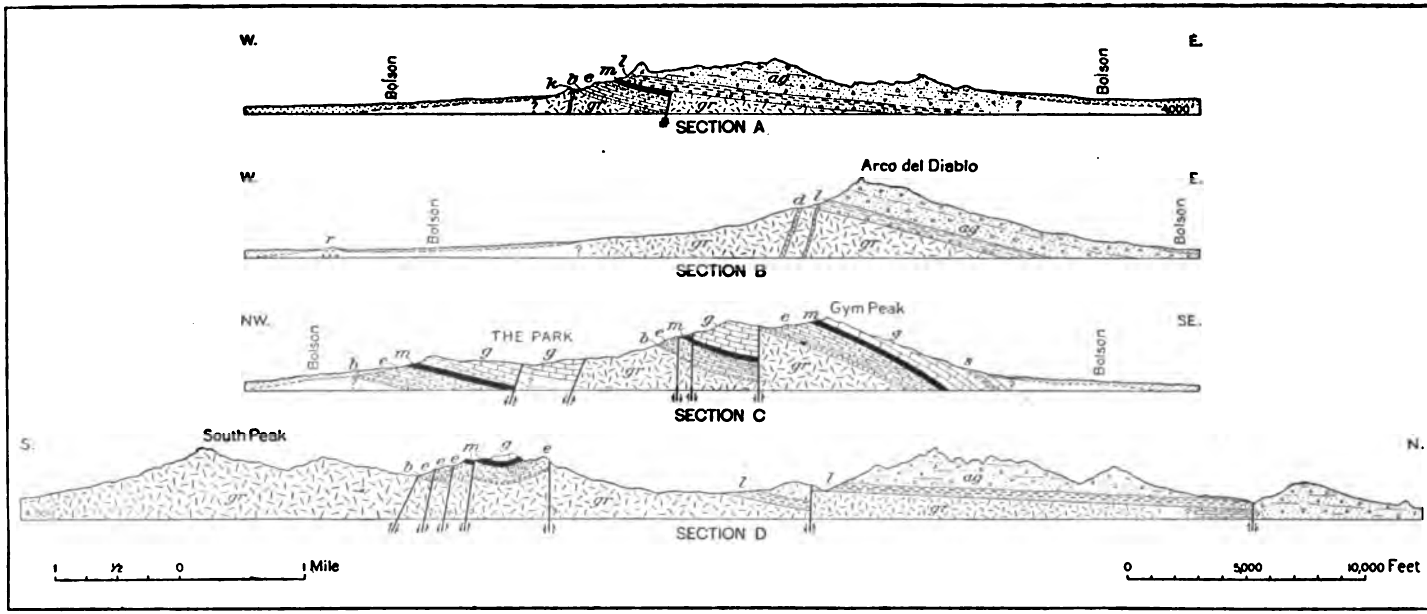

FIGURE 4.—Sections across the Florida Mountains. A, Through Capitol Dome; B, through Arco del Diablo; C, through The Park and Gym Peak; D, from south to north along the higher portion of the range. *b*, Bliss sandstone; *e*, El Paso limestone; *m*, Montoya and Fusselman limestones; *r*, felsitic rhyolite in White Hills; *d*, rhyolite porphyry dikes; *l*, Lobo formation; *g*, Gym limestone; *s*, black shale member; *k*, keratophyre; *gr*, granite; *ag*, agglomerate.

has a throw of 2,000 feet for part of its course, where it lifts the granite of the south end of the range so high that it abuts against upper beds of the Gym limestone. The fault plane dips 40°–70° S., and the granite is thrust over on the block to the north. The slope of this plane is well exposed in the spur southwest of The Park, where it dips 40° S., and also in places near the trail south of Gym Peak. This fault branches in The Park, but along its northwestern branch the uplift is on the northeast side, bringing up the granite and leaving a depressed wedge-shaped block of the Gym limestone and underlying rocks between the branches. The uplifted block on the northeast is tilted eastward at a moderately steep angle and half a mile west of Gym Peak is cut off by another fault, shown in the middle of section C, figure 4. This fault has a vertical uplift of about 2,000 feet and extends south of the great northwest fault. It branches just northwest of Gym Peak, one branch passing northeast and the other curving to the north; in both, the upthrow is on the east side. The eastern branch is well shown by the Montoya limestone abutting against the Bliss sandstone 1½ miles northeast of Gym Peak, and the western branch brings the Gym limestone and granite into contact east of the zinc mine. Apparently this fault branches again to the north, the western branch bringing upturned Montoya limestone against granite, and the eastern branch cutting off the El Paso limestone in the spur half a mile southwest of Byer Spring. The tilted block east of The Park is cut off on the north by a large fault that lifts the granite against the El Paso limestone on the main divide, as shown in section D, figure 4. The block is also crossed by several smaller step faults of 40 to 200 feet displacement, which trend nearly east (see section D, fig. 4), and are well exposed in the cliff east of The Park. They are lost in the Gym limestone slopes east of the summit. A fault trending northeast in the ridge extending northwest from The Park drops the Gym limestone to the level of the El Paso limestone. Another fault brings the El Paso limestone and granite into contact a short distance east and also southeast of Byer Spring. In the south slope a mile southeast of Byer Spring the plane of the fault appears to have a low dip to the east, for the granite and limestone contact slopes gradually down the hill nearly to the main northeast fault.

In the slopes 2 miles south by east from Gym Peak the granite and some outlying masses of the Gym limestone are intricately faulted together, so that wedges of the limestone are partly included in the granite and a tongue of the granite projects through the limestone at one place, the relations suggesting igneous intrusion. However, the limestone is not at all metamorphosed and the granite is a very coarse grained rock of the typical pre-Cambrian character. The southwestern mass consists of limestone and sandstone lying on

a gently sloping surface of granite. The larger eastern mass is underlain and overlain by granite on planes dipping gently eastward, and it is through this mass that a tongue of the granite has been forced, as shown in figure 5.

The limestone near the contact is shattered and brecciated for a foot or more and includes fragments of the granite. The granite is red, coarse grained, and massive, of the sort which constitutes a large part of the mountain, and while it is very much broken and crushed it shows no fining of grain such as occurs at igneous contacts. The precise method of faulting of the mass can not be ascertained, but doubtless the granite is a wedge between two fault planes carried westward into the limestone. These planes were part of a great fault similar to the one a mile farther north, but only these few scattered wedges of limestone remain to indicate its effects.

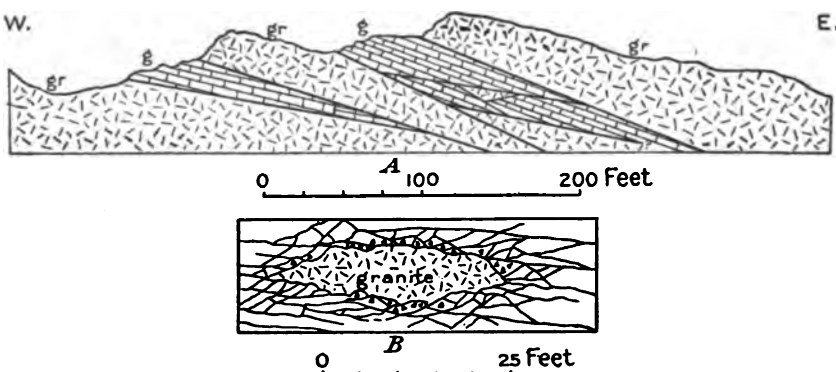

FIGURE 5.—Section showing relations of granite (gr) and Gym limestone (g) at southeast end of Florida Mountains, 2 miles south of Gym Peak. *B* shows relations of small mass of granite in center of *A*.

The fault near the north end of the Florida Mountains trends nearly east, and drops the agglomerate on the north side so that it abuts against older beds, from the Lobo formation to granite, on the south side. The maximum displacement is unknown, but at the granite contact the throw is at least 2,000 feet. Some of its relations are shown in section D, figure 4 (p. 74). The agglomerate and the Lobo formation are cut by another prominent easterly fault southeast of Arco del Diablo, the relations of which are shown to the right of the middle of section D. The beds on the south side are dropped about 400 feet vertically by this fault. The direction of the dip of the fault plane was not ascertained. A similar fault of much smaller throw crosses the range a mile southeast of Capitol Dome. Just south of Capitol Dome a northeast fault with vertical throw of more than 1,500 feet lifts the granite to the base of the Lobo formation.

The fault plane dips 45° NW., and along part of its course there is a dike of quartz porphyry 20 feet thick. In places the strata are upturned along the fault and dip northward. The fault is shown in figure 6.

The movement occurred long before Lobo time, for south of the fault the Lobo formation lies on the eroded surface of the granite. The plane of erosion crosses the fault and extends across the edges of the Montoya and El Paso limestones to the west and north. These relations indicate that during or after the faulting there was a great amount of erosion, which removed from the uplifted side of the fault the sandstone and limestone that overlie the granite just north and doubtless removed some of the granite also, for the granite plane beneath the Lobo formation may be much lower in the granite mass than the granite plane beneath the Bliss sandstone. Also at the time of faulting the locality may have been overlain by more or less Gym limestone. Large areas of this formation remain a few miles to the south, but it is absent in the overlap north of Capitol

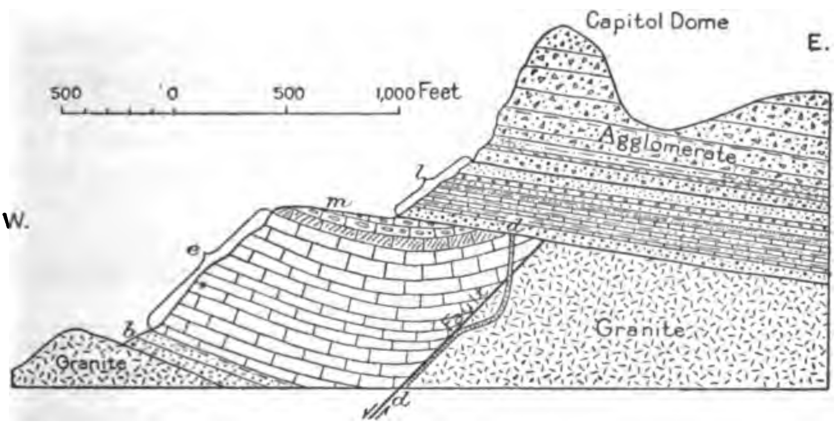

FIGURE 6.—Section at Capitol Dome showing relations of pre-Lobo fault. *l*, Lobo formation; *m*, Montoya limestone; *e*, El Paso limestone; *b*, Bliss sandstone; *d*, dike.

Dome, in which the Lobo formation lies on the eroded surface of the middle members of the Montoya limestone and still farther north extends somewhat lower over the El Paso limestone.

LITTLE FLORIDA MOUNTAINS.

The ridge known as the Little Florida Mountains consists of a thick sheet of felsitic or vitreous rhyolite included in the great agglomerate series. Apparently the horizon is somewhat above that of the agglomerate exposed in the Florida Mountains, as the latter range lies slightly west of the line of strike of the rocks in the Little Florida Mountains; but there may be a fault between the two ranges. The felsitic rhyolite appears to be mainly the product of one out-

flow, or a succession of outflows without intervening deposits, and probably it ends by thinning out not far beyond the termination of the ridge. Some other igneous masses are exposed in places on the west slope. The structure is shown in figure 7, in which section A shows the relations that prevail along the greater part of the ridge and section B shows certain local features of the faulted portion farther south.

All the rocks dip to the east at low angles, mostly less than 10°. In the northern part of the area the dips are from 10° to 20° north of east, but farther south the direction is in greater part due east. This dip carries the main sheet of felsitic rhyolite under the agglomerate to the east, so its thickness and extent in that direction are not known. The thickness in the middle of the mountains, as shown in section A, figure 7, is about 600 feet, and the amount gradually

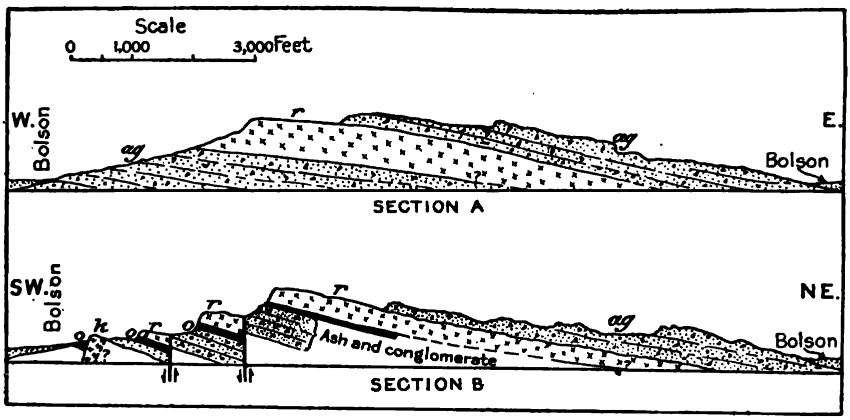

FIGURE 7.—Sections across the Little Florida Mountains. A, Across center of range; B, 1½ miles farther south. *ag*, Agglomerate; *r*, felsitic rhyolite; *o*, obsidian; *k*, keratophyre.

diminishes to the north and south. In the gap which crosses the ridge near its north end the thickness is less than 150 feet, but it increases again to double that amount in the knob to the northwest. Near the center of the mountains the underlying deposits of volcanic ash and other fragmental materials extend about halfway up the western slope, but the altitude of the contact diminishes to the north and south.

The relations shown in the western part of section B, figure 7, are due to two or more faults which appear to extend for some distance along the western slope of the southern half of the range. At and south of this place the rhyolite sheet is underlain by a flow of obsidian, 8 to 20 feet thick, which in turn lies on a bed of compact coarse volcanic ash of greenish tint. The faults cause the repetition of this characteristic succession in two prominent steps on the slope. The obsidian appears again at the edge of the bolson in the base of a

small knoll consisting of keratophyre, either a local sheet or a dike, probably faulted into its present position. A short distance southeast of the locality of section B the blocks shown in that section are displaced by a northeast fault. As the downthrow is on the east side the outcrops on this side are offset to the southwest. The blocks east of this transverse fault slope toward the south, and this structure, together with the thinning of the igneous sheet, causes the southern termination of the ridge. The easternmost of the longitudinal faults continues to be a conspicuous feature to the end of the ridge. Near the southeastern termination of the slopes there is a low spur caused by a dike of keratophyre, which cuts agglomerate and underlying volcanic ash for a short distance. It is a reddish rock jointed in vertical plates that strike a few degrees east of north.

Just west of the gap which crosses the northern part of the Little Florida Mountains there is a long, narrow outcrop of felsitic rhyolite, extending from the main felsite sheet some distance into the bolson on the west. It is probably a dike or feeder by which the sheet reached the surface at the time of its eruption. In the west slope, half a mile south of this outcrop, the strata under the main igneous sheet are traversed by a small dike of hornblende-biotite rhyolite, which appears to have disturbed the beds considerably and caused greatly increased silicification in them. There are several small outcrops of rhyolite, felsitic rhyolite, and andesite in the bolson a short distance west of the foot of the Little Florida Mountains, but they afford no evidence of their relations or underground extent.

TRES HERMANAS MOUNTAINS.

The ridges and peaks known as the Tres Hermanas Mountains occupy an area of about 35 square miles, lying 30 miles south of Deming. They extend about 10 miles from north to south, have a maximum width of about 5 miles, and rise abruptly from the great bolson. In a general way they are on the southern extension of the line of strike of the Florida Mountains, and doubtless there is an underground connection between the two ranges under the bolson deposits in the gap between them. The rocks and structure, however, are markedly different in most respects. In the Tres Hermanas Mountains there is a central igneous mass of coarse granite porphyry, flanked in part by andesites and felsitic rhyolite, in part by agglomerate, and in part by Gym limestone. The limestone has been upturned by the intrusion, and part of it near the contact has been metamorphosed to marble. There are no signs of the granite and earlier Paleozoic rocks, which are so prominent in the Florida Mountains,

and the agglomerate appears in the lower foothills on the southeast slopes and northeast end of the range. In general there is an igneous succession consisting of a central mass of granite porphyry, partly surrounded by andesite, then felsitic rhyolite, and last the basalt, which appears to underlie parts of the surrounding bolsons. The sections in figure 8 show the salient features of the structure along the slopes of the range, but most of the underground relations are not indicated by the outcrops.

The porphyry which constitutes the large central mass of the Tres Hermanas Mountains presents little evidence as to its structural relations. It cuts across and upturns the limestone on the northern slope and includes large fragments of that rock displaced some distance from their original position and metamorphosed to marble.

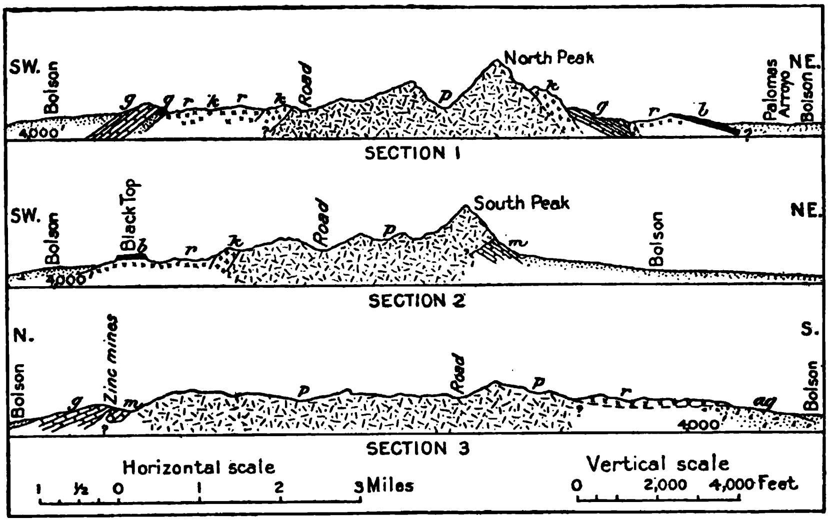

FIGURE 8.—Sketch sections across the Tres Hermanas Mountains. 1, From point southwest of Hancock mine through North Peak; 2, from Black Top through South Peak; 3, through center of range east of zinc mines. *p*, Porphyry; *r*, rhyolite; *b*, basalt; *ag*, agglomerate; *g*, Gym limestone; *m*, marble in Gym limestone; *q*, quartzite; *k*, keratophyre.

It is undoubtedly a thick body, probably connected underground with a large feeder or stock. The rock is classed as a granite porphyry or a quartz syenite porphyry by Lindgren, and while it is very different from the granite of the Florida Mountains it somewhat resembles the intrusives of Cooks Peak and Fluorite Ridge. Its character is very uniform throughout, its coarse grain, brownish color, and massive structure being shown in all exposures. Its topography is rugged, especially in the three prominent peaks shown in Plate IV, *B* (p. 12). Near Willow Spring the porphyry is flanked by typical agglomerate, but on its west side and along the north-

eastern spur of the range it is in contact with a sheet or dike of andesite several hundred feet wide. The relation of the three rocks was not observed, so that their relative age is not known. The andesite on the west side and northeast slope of the range separates the granite porphyry from a wide zone of felsitic rhyolite for most of its course. This rhyolite appears to be in an irregular sheet or a succession of sheets with some intervening fragmental deposits, and it is penetrated by dikes of andesite similar to that which separates the rhyolite and porphyry masses. In the southeastern part of the range and in its northeastern foothills the rhyolite lies on the great agglomerate. A thin sheet of basalt caps the rhyolite in the prominent butte known as Black Top, 2 miles west of Willow Spring, and also in the buttes just west of the Grade road 4 miles southeast of Waterloo.

In the vicinity of the old zinc mines at the north end of the range the limestone gives rise to a low ridge with its steeper slopes facing inward, toward the porphyry hills. The strata are cut off abruptly by the porphyry to the south and dip gently to the north, finally passing beneath the bolson deposits. Lindgren[1] has described the principal features at this locality in relation to the occurrence of the zinc ores. The main igneous contact extends eastward along the foot of the high ridge southeast of the mines. The limestone is considerably disturbed, showing many variations in dip, and evidently the contact is very abrupt and irregular, with projections of porphyry into the limestone. The dips range from 30° to 60° in amount and from northeast to northwest in direction. A sill or dike of the porphyry also cuts the limestone for 200 yards along an easterly course a few rods north of the main contact. For some distance from the igneous contacts the limestone is altered to a white, coarsely crystalline marble, and some beds show various secondary minerals, mainly garnet. At several places the more impure beds of limestone or shale are metamorphosed to a hornfels. The zone of alteration is very irregular in horizontal extent, but averages about 1,000 feet in width at one place mentioned by Lindgren. Marble and garnet appear in some of the beds half a mile north of the contact. Most of the metamorphism has occurred in the gap and on the south slope of the limestone hill. The principal zinc workings in the limestone are on the slope a quarter of a mile west of the little gap south of the limestone hill. The only sign of metamorphism at this place is the occurrence of bunches of wollastonite. Fossils of Carboniferous age were found by Lindgren in the limestones, even in greatly altered portions.

[1] Lindgren, Waldemar, The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 293, 1910.

Limestone constitutes a flanking ridge and spur extending northward from the high peak near the north end of the range. The strata dip at low angles to the east-northeast and east-southeast and at the south are cut off abruptly by a nearly vertical porphyry contact. Much of the limestone for 100 feet from the igneous rock is altered to a coarsely crystalline marble, as in the area near the zinc mine. To the east the limestone is penetrated by a thick mass of andesite which lies along the east side of the porphyry and projects northward from it. To the north this body of limestone dips beneath gray quartzite which extends as a prominent ledge trending east for some distance along the lower mountain slope and apparently is nearly if not quite cut off on the east by the north end of the andesite. The limestone of this area extends southward for several miles along the foot of the slopes of the central and southern high peaks of the range, and near the contact much of it is changed to white marble. In general the beds dip steeply to the east, or away from the igneous mass. There are several branch intrusions, and some large masses of marble are included in the porphyry, notably at the South Peak, where the marble extends halfway up the slope and is in one place 200 feet wide. The south contact of this mass is very irregular, but on the north side the contact extends almost vertically up the slope. In places there is considerable yellowish-green vesuvianite or garnet in veins 6 inches to 3½ feet wide along the junction of the two rocks. In the upper part of the marble mass there is a nearly vertical hole about 25 feet in diameter and 80 feet deep. It was caused by solution of the limestone. At the bottom there is considerable bat guano, which has been mined to some extent. More or less marble appears along the contact low on the east slope of the middle peak, and one thin bed of the limestone at this place is changed to a heavy white rock, mostly garnet, vesuvianite, and diopside. Many fossils occur in associated strata here and farther north. The small mass of limestone that crops out a mile east of the Hancock mine lies along the west margin of the porphyry intrusion.

The westernmost range of the Tres Hermanas Mountains lies a mile west of the Hancock mine. It consists of 600 to 800 feet of the Gym limestone, dipping steeply westward. The rocks are light colored and include some brecciated beds. They have yielded late Pennsylvanian fossils. Under this limestone is a gray to reddish quartzite, in part brecciated, which crops out as a cliff along a low ridge on the east side of this westernmost range and shows a thickness of 40 to 50 feet. Next east of it is a valley occupied by the felsitic rhyolite, which extends in a broad zone along the west side of the Tres Hermanas igneous area. The relation of the rhyolite to the limestone is not exposed, but some features suggest that they are separated by a fault trending northwest.

VICTORIO MOUNTAINS.

The main ridge of the Victorio Mountains consists of a tilted sheet of andesite and its south slope and the scattered knobs to the south are of sandstone and limestone. The principal structural features are shown in the sketch map and sections forming figure 9.

The prominent northern ridge consists of a massive sheet of hornblende andesite dipping 20°–25° NNE. It is about 200 feet thick and gives rise to the crest and south slope of the ridge, including the prominent Victorio Peak. To the west it is underlain by a thin sheet of felsitic rhyolite, and there is another thin sheet of the rhyolite near the northwestern termination of the ridge. This upper sheet is 10 feet thick and nearly pure white in color. It crops out about half a mile south of the railroad, which passes just north of the end of the igneous outcrop. The main andesite sheet lies on about 700 feet of shales and sandstones, largely of reddish tints, which dip 15°–20° slightly east of north, having the same or nearly the same attitude as that of the andesite. Dark purplish-brown fine-grained massive shales or sandstones predominate, but the beds include several layers of coarse conglomerate, containing bowlders of andesite, and some greenish sandstones near the top contain conglomerate carrying pebbles of fossiliferous Paleozoic limestones. This formation is underlain by limestones that begin abruptly, and at the contact, which is well exposed near the locality of section 1, figure 9, there is but little evidence of unconformity and no suggestion of a fault.

The structure of the limestone ridges and hills constituting the southern part of the range is complicated by several faults and some overlapping, and the outcrops are not sufficiently continuous to exhibit the relations fully. In Mine Hill there appears to be a regular monocline, and the southward-dipping Fusselman limestone with characteristic coral fauna on the south slope is underlain by cherty and siliceous beds of the Montoya limestone, which constitute the north summit, north slope, and east and west sides. The underlying El Paso limestone crops out in the hill next to the north, dipping to the south and southeast and apparently in regular succession. The strata appear to be cut off on the west side of the monocline by a fault that extends along the foot of the slope with a north-northeasterly course and has the uplift on the east side. It is well shown in the shaft on the Lesdos-Rambler claim. Owing to this fault, the outcrop of the Montoya limestone on the west side of the fault is offset to the north, and it extends along the southern slopes west of the road to and beyond the line of section 1, figure 9. For most of its course on this side of the fault the limestone dips at first to the southwest and then to the north. The inclination is

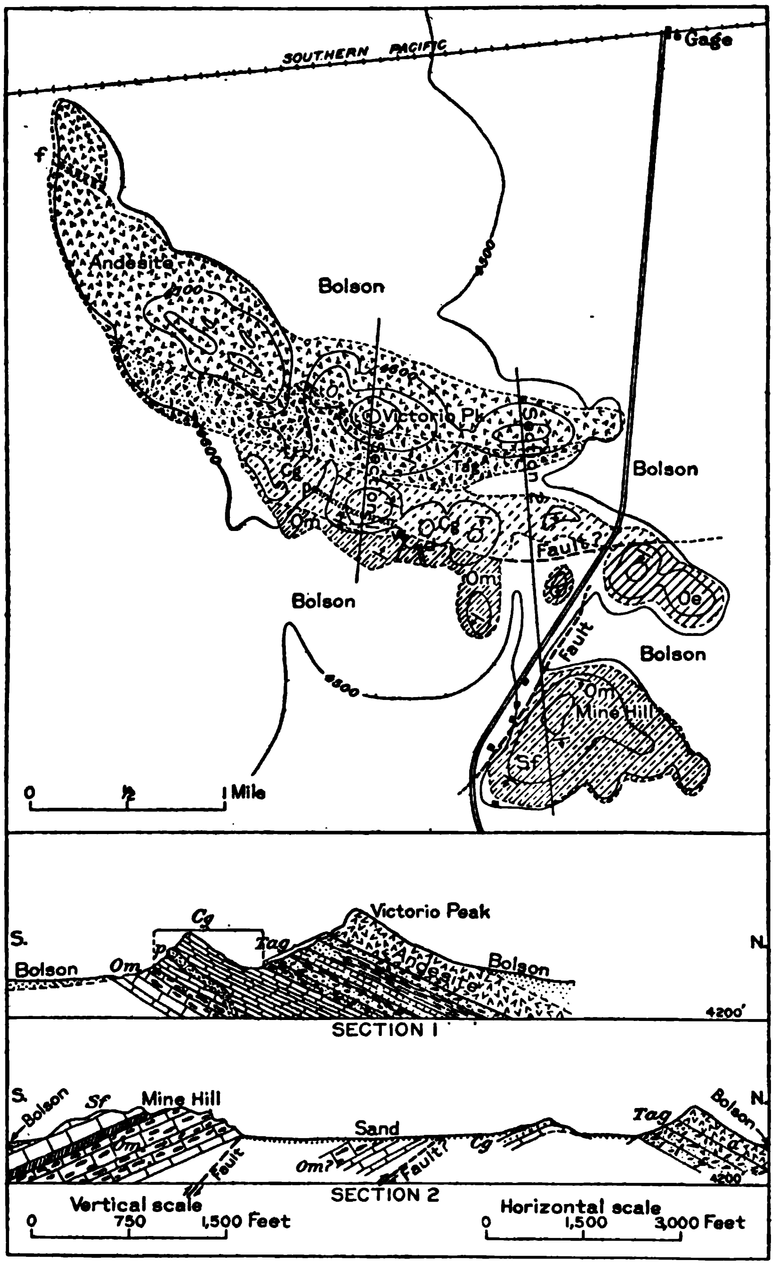

FIGURE 9.—Sketch map and cross sections of Victorio Mountains. The contour lines, 100 feet apart, are based on aneroid readings. *a*, Andesite; *Tag*, agglomerate, shale, and sandstone; *Cg*, Gym limestone; *Sf*, Fusselman limestone; *Om*, Montoya limestone; *Oe*, El Paso limestone; *p*, porphyry; *f*, felsite; *d*, dike of andesite and quartz porphyry; *w*, quartz vein with wolframite.

steep near the wolframite pits, but farther west it is only from 15° to 20°, as shown in section 1. In this area the cherty beds of the Montoya are overlain by the Gym limestone, and while some Fusselman limestone may intervene, no direct evidence of its existence was obtained, and it appears to be cut out either by faulting or unconformable overlap. Not far above the fossiliferous layer in the Montoya is a bed of gray sandstone, which extends all along the south slope of the range and crosses the road half a mile north of the mining camp. Near this road and for a few rods to the east there is a low anticline, on the south side of which the dips are to the south-southeast. East of the road the sandstone and associated conglomerate, limestone conglomerate, and fine-grained sandstone appear to pass under the El Paso limestone, a relation probably due to overthrust of the limestone along a branch of the fault above mentioned. Some distance west of the road the sandstone member is overlain by 300 feet of limestone, which constitute the three round knobs on the southern ridge of the mountains. Some of the beds are very fine grained and slabby; others are brecciated and massive. They yield abundant Manzano fossils, by which they are identified as the Gym limestone. In the highest knob, as shown in section 1, figure 9, the dip is 20° N., and the limestone passes under the conglomerates and shales. In the middle slope of this knob and to the west the limestones are parted by a 60 to 80 foot sill of porphyry similar to the rock in Fluorite Ridge. A short distance southeast, on the slope of the middle knob, are two small dikes, one of which is quartz porphyry and the other gray andesite, side by side and trending nearly due north.

FLUORITE RIDGE.

Fluorite Ridge consists of a thick central mass of porphyry so intruded as to cause an irregular dome-shaped uplift, elongated to the northwest and southeast. The strata on the south and east sides of the dome stand nearly vertical, but those on the north and west sides have more moderate dips. The plane of intrusion is low in the Paleozoic strata at the southeast end of the uplift, but it rises rapidly toward the north and west to the base of the Sarten sandstone. Along part of the southwest slope of the ridge, where the porphyry extends down to the edge of the bolson, the structural relations are not revealed. At the south end of the ridge two or three faults cause considerable complexity of structure. The salient structural features are shown in figure 10.

The crystalline rocks exposed in the lower slopes southwest of Fluorite Camp are red granite and diorite, in part gneissic and in places porphyritic. They are cut off on the north by a vertical

fault of slight amount, which at one point brings them into contact with beds as high as the medial member of the Bliss sandstone. In some places there are limy shales at the contact, in others reddish quartzitic sandstone. The sandstone extends in conspicuous ledges along the slope of the ridge for half a mile, at one place offset to the north by a cross fault. The beds dip steeply north and present a succession comprising the El Paso limestone, Montoya limestone, and cherty beds, probable Fusselman limestone, Percha shale, and the lower portion of the Lake Valley limestone. Some of the beds are greatly squeezed, notably the El Paso limestone, which presents a thickness of only 400 feet at the east end of the ridge and somewhat less to the west. The cherty members of the Montoya limestone are very conspicuous in the high knob at the southeast corner

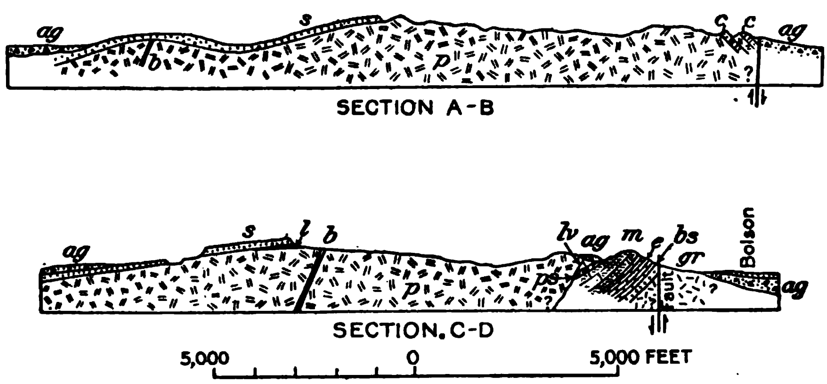

FIGURE 10.—Sections across Fluorite Ridge. A–B, Section west-northwest to east-northeast; C–D, section from northwest to southeast across east half of the ridge. *gr*, Granite and diorite; *bs*, Bliss sandstone; *e*, El Paso limestone; *m*, Montoya limestone overlain in part by limestone of undetermined age; *ps*, Percha shale; *lv*, Lake Valley limestone; *l*, Lobo formation; *s*, Sarten sandstone; *ag*, agglomerate; *b*, basalt dike; *c*, chert.

of the ridge. There appear to be a westerly fault, or two of them, near the north end of this limestone knob, but owing to lack of evidence as to the age of the limestones north of the Montoya ledges the presence of the fault is not certain. The plane of porphyry intrusion descends considerably across the beds in the saddle at the north end of this knob, but in the slopes just east and west of the saddle the Percha shale appears; and as the plane of porphyry intrusion rises still higher to the northeast, several hundred feet of the lower part of the Lake Valley limestone is exposed. Farther east and north are several great masses of white silica rock, most of it entirely surrounded by porphyry. Its character indicates that it is limestone replaced by silica. One of these masses extends as a foothill ridge for some distance north of Fluorite Camp, where at one place it is 90 feet thick. A small outlying mass rises above the

agglomerate a quarter of a mile east of the camp. The age of this silica rock is not known; it may be either Lake Valley or Montoya, but is presumably the latter.

A fault of considerable magnitude, with downthrow on the east, extends along the east side of Fluorite Ridge and cuts off the granite, sandstones, and limestones, which therefore abut against the porphyry. Possibly, however, the porphyry was intruded since the faulting. There are some indications that the fault or a branch of it trends northeastward just north of Fluorite Camp and passes east of the silica ridge; and, if so, it may be a continuation of the great fault that passes through Fryingpan Spring. The slickensided plane of this fault is exposed in some of the fluorite workings just west of the camp, but whether or not it cuts the agglomerate or separates it from the porphyry is not known. The agglomerate appears all around the flanks of Fluorite Ridge, but the exposures are so obscure that its relations to the porphyry are not exhibited; in places the two are separated by faults. No fragments of the porphyry of the kind forming the intrusive mass were observed in the agglomerate—a fact which suggests that the porphyry may be younger than the agglomerate, or at least than the portion in this vicinity. A mass of breccia of considerable size lies on the south slope of Fluorite Ridge, just west of the limestone knob that constitutes the southeast end of the ridge. This breccia consists mainly of large masses of gneiss as well as abundant smaller fragments of the same rock, and was apparently brought up by the porphyry as a friction breccia from the pre-Cambrian basement, which is not far below.

The structure of the central part of Fluorite Ridge (see section A–B, fig. 10) is very different from that of the east end. There is a long slope of porphyry down to the bolson on the south side, and the Sarten sandstone dips steeply down on the north side. The sandstone extends to the top of the ridge, where it presents a high cliff to the south as well as to the east and west. On the east side of this high central ridge there is probably a cross fault continuous with the fault that crosses the road 2 miles farther north. At one point in the cliff at the summit of Fluorite Ridge the sandstone is underlain by a small amount of conglomerate of the Lobo formation lying on the porphyry. To the west of the high central ridge the plane of the porphyry intrusion descends to the point where the Sarten sandstone arches over the igneous body in an anticline that pitches down into a shallow cross syncline in the gap across the west end of the ridge. The porphyry rises again a short distance to the west, creating a low ridge with crest and north slope of porphyry. Large masses of agglomerate rise above the bolson along the base of this

portion of the ridge, especially on its north side. The contact of the porphyry and the Lobo and Sarten formations is well exposed in places on the south slope of the central ridge. The contact is very irregular, and in places long projections of the porphyry extend into the sedimentary rocks. Near the contact the sedimentary rocks are considerably altered and the porphyry is finer grained.

The Sarten sandstone of the central peak of Fluorite Ridge dips north and is probably cut off on the east by a fault that crosses the ridge and passes northward to and through the Pony Hills. The sandstone extends some distance north from the foot of the ridge in a line of low cliffs facing east and marking this fault, which is traceable to and beyond the old Butterfield road. Near that road granite crops out on the east side of this fault, and this rock also appears farther west in the midst of the Pony Hills and constitutes the northern part of the ridge north of China Tank.

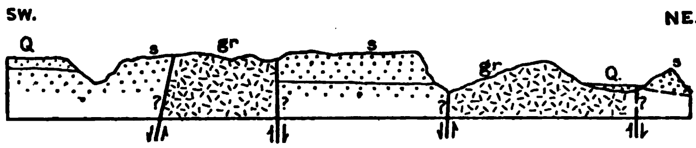

FIGURE 11.—Section across the Pony Hills, 13 miles north of Deming. Q, Bolson deposits; s, Sarten sandstone; gr, granite.

PONY HILLS.

The small group of low hills in the center of the structural basin lying between Sarten Ridge and Fluorite Ridge consists of outcrops of the Sarten sandstone and granite. The relations of the rocks are considerably obscured, especially to the west, by gravel and sand of the bolson deposits. The most conspicuous feature is a cliff of the Sarten sandstone extending to the old Butterfield road and nearly continuous southward with a low spur of Fluorite Ridge. Low hills of gneissic granite rise just east of the sandstone area, and there is a fault separating them, as shown in figure 11.

In the rolling hills west of the main body of sandstone there are outcrops of schistose granite, in one place penetrated by a dike of diorite. The sandstone lies on a sloping plain on the granite, a relation which may indicate overlap but more likely is due to faulting. The basal sandstone is coarse, but not more so than some of the beds at high horizons. Much of the contact of the larger mass of sandstone and of the smaller masses to the west is covered by sand and gravel. The sandstone in the two knolls northeast of the road is typical Sarten sandstone, but its relations to the granite are not revealed.

GOAT RIDGE.

Goat Ridge rises about 500 feet above the bolson, and is on the prolongation of the strike of the anticline of Fluorite Ridge. It is an elongated dome with axis trending northwest and brings up the Sarten sandstone. The slopes and crest consist of rocky ledges of sandstone and quartzite, which are eroded through along the west slope and in the south end of the ridge, exposing the underlying Lobo formation nearly if not quite to its base. At the foot of the ridge is exposed more or less agglomerate, which at the north end is cut by a dike of keratophyre extending northeast to and beyond the road.

GOODSIGHT MOUNTAINS.

Only a brief reconnaissance was made of the Goodsight Mountains, but it was found that they consist of a mass of agglomerate capped by a sheet of basalt dipping east at a low angle. Their highest part is at Goodsight Peak. There is a gentle slope to the east on the

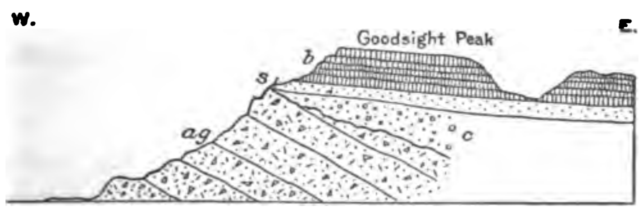

FIGURE 12.—Sketch section through Goodsight Peak. *b*, Basalt lava flows; *s*, gray sandstone; *c*, conglomerate; *ag*, agglomerate.

uplifted basalt sheet and a steep slope on the west side in the underlying deposits of agglomerate and ash. In the valley east of the mountains the basalt finally passes beneath bolson deposits of gravel, sand, and clay. The section at Goodsight Peak given in figure 12 shows the main structural features of the range.

The agglomerate in slopes below Goodsight Peak is a very massive rock and consists mostly of large and angular fragments of hornblende andesites in a more or less crystalline matrix. It is precisely similar in aspect to the agglomerate constituting the north end of the Florida Mountains and appearing in Cooks Range 2 miles southwest of Fort Cummings and at other places. It is overlain unconformably by gray conglomerate and 40 feet of soft gray sandstone, both consisting largely of volcanic materials. Probably this deposit is of Quaternary age. The basalt is in three sheets, 200 feet thick in all, and probably represents three effusions of lava. Much of it is vesicular. Just east of Nutt there is a long railroad cut through the ridge which reveals a thick mass of agglomerate

containing fragments of hornblende latite and andesite. This is capped by the main basalt sheet farther east.

RED MOUNTAIN.

Red Mountain consists of a large mass of nearly white felsitic rhyolite rising abruptly out of the bolson 10 miles southwest of Deming. Much of the rock is so jointed that it weathers into nearly vertical plates and slabs, mostly trending north. At its northeast end the mass appears to dip to the northwest, but elsewhere it presents no suggestion of structure and there is no evidence as to its thickness. At the base of the slope on the south side there is a small exposure of agglomerate, presumably underlying the rhyolite. This material is dark bluish gray, and the fragments, which are all angular, consist of andesite or latite. At other points the rhyolite or its talus extends down to the edge of the bolson deposits. It is probable that the Red Mountain igneous mass was extruded in a highly viscous condition, so that it piled up thickly without extending far beyond its present area. The date of its extrusion and its subsequent history are not known, but if it is of the same age as the other masses of similar rock it was once covered by agglomerate.

BLACK MOUNTAIN.

Black Mountain, which rises high above the bolson 8 miles northwest of Deming, consists of a sheet of basalt about 250 feet thick, capping a mass of volcanic ash and sand. Apparently it is the remnant of a flow or series of flows which originally had considerably greater extent. At the west end of the mountain the base of the basalt is about 500 feet above the bolson, and the long slope below shows deposits of sand and volcanic ash and tuff, largely covered by talus of the black rock from the cliffs above. The igneous sheet dips to the east at a low angle, and this dip finally carries it beneath the surface at the east end of the mountain. How much farther it extends underground and its former extent to the west are not known. A small outlying mass, separated by erosion, caps a knob on the south-central slope of the mountain. A small area of similar rock appears in two low buttes 2 miles northwest of Black Mountain, and there may be underground connection between the two areas. The basalt of Black Mountain is mostly dense and massive, but portions are somewhat cellular, and in a few places, especially near the basalt contact, the cellular structure is so highly developed that the rock is a scoria or pumice. The basal contact appears to be a relatively smooth plane, so far as can be inferred from widely scattered exposures. The underlying beds of fragmental material dip east at about the same angle as the igneous sheet. Their principal com-

ponent is sand, more or less mixed with volcanic material in the form of ash and pumice, and some portions contain cross-bedded pebbly streaks. Low down at the southwest corner of the mountain there are exposures of igneous rocks cutting these sediments. One mass is a dark-gray obsidian or perlite in a sheet 4 or 5 feet thick. It has a circular outcrop, presents low cliffs to the south and west, and apparently is connected with a vertical dike on its east side. In the center of this area is a small body of light-colored intrusive biotite rhyolite with pronounced cleavage into slabs. A few rods southwest of this locality there is a small knob about 50 feet high separated from the foot of Black Mountain by a low saddle. This knob consists of a vertical dike of basalt 15 to 20 feet wide, cutting the agglomerate along a northerly course. Possibly this was a feeder for the main outflow of the basalt of Black Mountain, but the surface connection has been removed by erosion.

SNAKE HILLS.

The Snake Hills, sometimes called the Rattlesnake Hills, consist of a ridge of limestone which crops out across the southern part of T. 24 S., R. 10 W. Its length is about 2½ miles, and the knobs of the higher

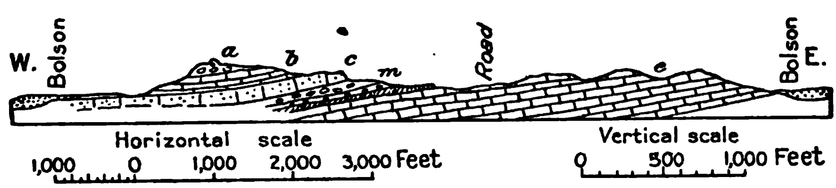

FIGURE 13.—Section through Snake Hills. *a*, Limestone with chert in large bodies; *b*, limestone with chert mostly in thin alternating layers; *c*, massive dark sandy limestone; *m*, Montoya limestone; *e*, El Paso limestone.

summits are mostly from 150 to 200 feet above the plain. The east half consists of the El Paso limestone dipping 5° to 8° W., and thus exposing about 700 feet of beds. The west half consists of the overlying Montoya limestone, which first dips west and then is flexed in a low dome, deeply eroded in its center and almost flat along the west side of the ridge. The cherty beds of the Montoya limestone form the dominant topographic features, giving rise to the high central buttes. The structure is shown in figure 13.

The succession of rocks in the Montoya limestone comprises a dark massive limestone at the base, next a lower chert member, then a medial member of dark massive limestone presenting low cliffs, and at the top a highly cherty member capping the highest knob and extending down the west end of the ridge. This rock appears again in a small outcrop rising out of the bolson a few rods northeast of

the west end of the ridge. The basal contact of the massive lower member of the Montoya limestone on the El Paso limestone shows evidence of unconformity by erosion, although there is no notable discordance in dip.

KLONDIKE HILLS.

The Klondike Hills, near the west edge of the county, consist mainly of two narrow limestone ridges trending east and in part rising into buttes of considerable prominence. The principal structural features are shown in figure 14.

The granite exposure occupies a small area in the middle of the hills, a short distance west of the southern high knob. The rock is red to gray in color, and although part of it is coarse grained, much of it has a well-developed banded structure and may be classed as gneiss. The granite appears to be cut off on the west by a slight fault, but to the east it passes under brown sandstone (the Bliss),

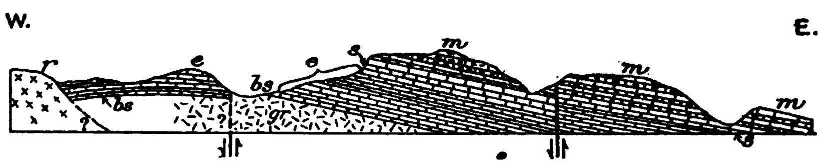

FIGURE 14.—Section through Klondike Hills. *gr*, Granite and gneiss; *bs*, Bliss sandstone; *e*, El Paso limestone; *m*, Montoya limestone (sandstone, dark limestone, and cherty limestone); *s*, sandstone at base of Montoya limestone; *r*, felsitic rhyolite.

which is only a few feet thick and is largely obscured by talus. Next to the east is an eastward-dipping succession of typical El Paso limestone several hundred feet thick and cherty Montoya limestone apparently 150 feet thick. At the base of the Montoya is sandstone 6 to 8 feet thick lying on an irregularly eroded surface of the El Paso limestone and grading up into 30 or 40 feet of dark sandy limestone. These two members are supposed to represent the dark basal limestone at many other localities. The purer Montoya beds contain abundant fossils. The cherty beds give rise to the two conical high buttes and the rugged ridges at the east end of the hills. To the east there is some cross faulting, which is clearly indicated by the reappearance of the basal sandstone of the Montoya on the slope of the southeastern ridge, and by the duplication of certain fossiliferous layers.

The western portion of the Klondike Hills consists in part of the characteristic El Paso limestone dipping mainly at low angles to the north and cut off to the southwest by rhyolite, which crops out in an area about half a mile long. In places near the igneous rock there has been a large amount of siliceous replacement in the lime-

stone, doubtless due to the secondary deposition in connection with the intrusion.

CEDAR GROVE MOUNTAINS.

The Cedar Grove Mountains were examined only at a few widely separated localities. The range is a single-crested ridge extending continuously across the southwest corner of the county to Carrizalillo Spring. It consists mainly of a long sheet or succession of sheets of latite lying on agglomerate. In places the latite is underlain by andesite and rhyolite. The dip is toward the northeast at a low angle, which carries the main igneous sheet below the agglomerate, but in places it is overlapped by bolson deposits. A sketch section made along the main road through the Williams ranch is given in figure 15.

About 20 feet of the rhyolite is exposed at the foot of the mountain slope overlain by 60 feet of red to gray coarse breccia and tuff

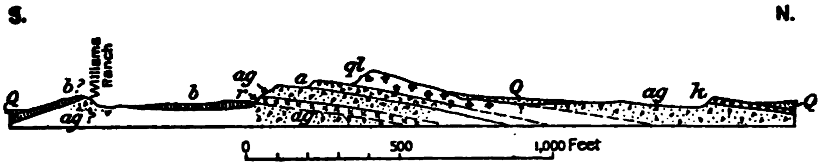

FIGURE 15.—Sketch section across the Cedar Grove Mountains north of Williams ranch. Thicknesses approximate. Vertical scale exaggerated. *ag*, Agglomerate; *ql*, quartz latite; *a*, hornblende-augite andesite; *k*, keratophyre; *b*, basalt; *r*, hornblende-biotite rhyolite; *Q*, bolson deposits.

of the agglomerate series. The sheet of hornblende andesite may be separated from the hornblende latite by tuff, but the contacts are not exposed. The latite constitutes the crest and northeastern slope of the main ridge, and evidently is a very extensive flow, for it was observed at intervals to the south end of the range. The relations at its top are not well exposed, owing to the covering of bolson deposits and talus, but above it there is a thick mass of agglomerate penetrated by various igneous masses and overlain by a thin sheet of dark fine-grained keratophyre. The light-gray agglomerate is well exposed in the slopes below this sheet of keratophyre along the little valley extending west toward the Cedar Grove ranch. In the prominent ridge west of that ranch the latite is overlain by a coarse pink rhyolite, although possibly the two masses are separated by a fault. At Smith's ranch the igneous rock constituting the crest and east slope of the mountain is a thick sheet of latite. It is overlain by a succession of andesite, rhyolite, trachyte, and latite sheets, in all about 160 feet thick and dipping gently to the east. These rocks are overlain by tuffs and agglomerate, with thin flows of rhyolite

extending south up the valley to the Cox ranch and beyond. At the Cox ranch a sheet of the rhyolite is especially conspicuous. It gives rise to a line of knobs and foothills at the base of the northeast slope of the mountains in this region. A short distance northeast of the main Cedar Grove Mountains, or on the east side of the valley referred to above, there is a parallel ridge extending north from Hermanas nearly to the main road southwest of the Klondike ranch. It is not as high as the mountains, and its crest is broken into knobs and ridges of moderate prominence. This outlying ridge is capped by a thick sheet of basalt lying on fragmental volcanic deposits and dipping gently to the northeast under the bolson. Another area of basalt occurs on the south side of the Cedar Grove Mountains about the Williams ranch, and a small mass appears near the main road 3 miles southwest of the Klondike ranch.

CARRIZALILLO HILLS.

The Carrizalillo Hills form a detached southern continuation of the Cedar Grove Mountains, and the structure and rocks are similar. The northern group of hills consists of hornblende latite and the southern group of hornblende-biotite rhyolite and rhyolite tuff. Both latite and rhyolite lie on tuffs and agglomerate, and all the beds dip eastward at low angles. There is some faulting, but the relations of the faults were not ascertained. The latite sheet, or a dike of that rock, crosses the valley just below Carrizalillo Spring, and doubtless it is the presence of this barrier to the underflow that brings the water to the surface.

SIERRA RICA.

The north end of the Sierra Rica extends a short distance into the southwest corner of Luna County and consists of Lower Cretaceous strata. The principal rock outcrops are two prominent knobs or buttes, shown in Plate VII, *A* (p. 15), and there are several smaller ridges, all in an area of about 2 square miles. The most abundant rock is limestone, which constitutes the large buttes. It is of a light blue-gray color and is in part massive and in part thin bedded. It contains Trinity fossils. There is a general dip of 4°–5° N. in most of the area, but near the international boundary line the monocline gives place to a low anticline. The axis of this flexure trends east and passes through a small gap a quarter of a mile north of boundary stone 39. East of the southeast end of the southern high butte there are slopes and a valley of limy shale, east of which sandy limestone rises in low ridges. This rock is highly fossiliferous, some of the upper layers being filled with large Exogyras believed to be

of Washita age. If this correlation is correct these beds are separated from the older limestone of Trinity age by a fault with downthrow on the east side. A mile east of boundary stone 39 there is a mineral lead trending northeast, along this fault or a large joint plane. On its east side is a gray quartzite which crops out in the axis of the anticline a quarter of a mile northwest of boundary stone 38. The vein is of varying width and consists of iron oxides carrying disseminated bodies and grains of fairly rich argentiferous galena. It has been worked in a small way for several years, apparently without much profit, if any. The diggings are known as the International mine. Near the mine and west of it are small dikes of felsite. Boundary stone 38 is on a knoll which is the easternmost outcrop of the area. It consists of gray slabby limestone.

GRANDMOTHER MOUNTAINS.

The Grandmother Mountains, in T. 23 S., Rs. 12 and 13 W., consist of a group of peaks and ridges composed of felsitic rhyolite. The rock rises abruptly out of the bolson 6 miles north of Gage and presents no evidence of its relations to the sedimentary rocks or to the agglomerate which probably underlies most of the area. It was not possible to determine the structure of the igneous mass, but it appears to be a center of eruption and possibly an irregular series of stocks or dikes and sheets. The rock is very uniform in character throughout and includes but little fragmental material.

COW CONE AND COW SPRING HILLS REGION.

The conspicuous conical butte known as Cow Cone, in the northwestern part of the county, and the knobs and ridges southeast of it, comprising most of the Cow Spring Hills, are masses of felsitic rhyolite. The high ridge at the south end of these hills is a widespread sheet or succession of sheets of hornblende-biotite rhyolite lying on agglomerate and other fragmental deposits. Cow Cone and the adjoining knobs appear to be stocks or fragments of sheets. The cone presents a strongly marked bedded structure, with dips of about 30° W. The rock on top is pink and flaky and the material lower down is gray and massive. The rocks in the knob next east are nearly white. Cow Spring Hills begin in a high ridge just south of Cow Spring. The rock here is coarse grained and massive and appears to be an irregular sheet extending 6 miles along its southeasterly course. It has various minor irregularities, due partly to intercalated fragmental beds, and appears to be cut off by an east-west fault near the south line of T. 22 S., R. 12 W. Doubtless it underlies the area on the east which is covered by bolson deposits, for it is exposed by erosion in the hollow in that direction.

South of the supposed fault just mentioned rises a prominent escarpment, which extends to the west end of the ridge and thence swings around its point and for some distance down the northeast side of the Cow Creek valley. This escarpment shows 200 to 300 feet of volcanic ash, tuffs, and other fragmental beds, in large part water-laid, overlain by a thick sheet of rhyolite. This sheet and the underlying deposits slope to the southeast and finally pass beneath the bolson deposits. The igneous rock is a coarse-grained massive hornblende-mica rhyolite, apparently in two sheets each about 60 feet thick, with an intervening sheet of finer-grained rock 30 feet thick. The top flow is light colored; the bottom one has a reddish tint and weathers into large blocks and cliffs. A sheet of rhyolite similar to the lower member crops out along the north side of the valley in the northern and eastern parts of T. 22 S., R. 12 W. Part of it lies on white massive agglomerate, which in turn is underlain by felsitic rhyolite, probably in a northern extension of the great flow of the Cow Spring Hills. If this is the case, it indicates that in this general region there is a succession of felsitic rhyolite, agglomerate, and hornblende-biotite rhyolite. Not far above the hornblende-biotite rhyolite at the locality above mentioned is a sheet of fine-grained dark-brown basalt 40 feet thick. It lies on conglomerate and dips 10° N. 20° E. Three miles farther west there is a 40-foot sheet of very fine grained black basalt, lying on a few feet of light-colored agglomerate, which in turn is underlain by felsitic rhyolite that forms part of the Cow Spring mass. The black basalt at this place is full of flow cracks and lines, which appear plainly in the weathered rock. A mile to the west is exposed a mud flow, which may be part of the same igneous extrusion. It lies on several hundred feet of sandstone and conglomerate, white, red, and green in color, probably members of the great agglomerate series.

ARENA HILLS.

East of Arena, in the southeast corner of the county, there is a low bench or step rising to a wide plateau, in places 200 feet higher than the bolson at and west of Arena. The west slope and surface of the plateau is made up of sand, but out of it rise scattered knolls of rocks of various kinds, which probably indicate the existence of a long rocky ridge nearly buried by Quaternary deposits. One large knoll rising 200 feet above the sandy surface east of Arena consists in part, or perhaps entirely, of quartz monzonite porphyry somewhat similar to some of the rock of the Cooks Peak region. A small knoll at international boundary stone 14 consists of hornblende andesite, and two small ridges northwest of boundary stone 15 are made up of felsitic rhyolite.

There are several prominent peaks and ridges northeast of the Birchfield ranch. The westernmost one rises 300 feet above the bolson and consists entirely of limestone. The beds dip 20° west by south, and the thickness exposed is about 1,000 feet. The rocks are blue-gray of various tints, and the bedding varies from slabby to massive; near the top are some ledges of coarse limestone conglomerate. A few fragmentary fossils observed appear to be of Pennsylvanian age, but this identification is by no means certain. A short distance east of the limestone ridge is a butte showing some agglomerate and a sheet of soda granite porphyry. Farther northeast, along the east margin of the county, are some other outcrops of igneous rocks rising above the plateau, but they were not visited. The plateau here consists partly of a soft sandstone with some conglomerate layers which may be older than Quaternary, but the relations were not ascertained.

BURDICK HILLS.

The Burdick Hills are a series of outlying knolls at the edge of a higher level or step in the plain of bolson deposits south of the valley of Palomas Arroyo west of Iola. These hills consist largely of small masses of various igneous rocks, which show but little of their relations to one another. There is an eastern or outer rim of hornblende latite, some dikes and probable stocks of felsitic rhyolite and quartz porphyry, and some small showings of hornblende-biotite rhyolite. No contacts are clearly exposed except in the larger area in the southeast corner of T. 26 S., R. 11 W., where the agglomerate appears to be cut by dikes of rhyolite and quartz porphyry. At one point farther west there is a small showing of black basalt similar to that which appears in Black Mountain and at several other places in the county.

MIDWAY BUTTES.

The Midway Buttes are knobs of felsitic rhyolite rising out of the bolson 3 miles south-southwest of Iola. They appear to be stocks, but no details of structure or relations are revealed.

GEOLOGIC HISTORY.

General sedimentary record.—Some of the rocks appearing at the surface in Luna County are of sedimentary origin; others are igneous outflows or intrusions. The sedimentary rocks consist of limestone, sandstone, shale, sand, loam, and gravel, all presenting more or less variety in composition and appearance. The principal materials of which they are composed were originally gravel, sand, or mud derived from the waste of older rocks, or chemical precipitates from salty waters.

These rocks afford a record of geologic events in the region from pre-Cambrian time to the present. The composition, appearance, and relations of the strata indicate in some measure the conditions under which they were deposited. Sandstone ripple-marked and cross-bedded by currents and shale cracked by drying on mud flats were deposited in shallow water; pure limestone indicates open seas and scarcity of land-derived sediment. The fossils which the strata contain may belong to species known to inhabit waters that are fresh, brackish or salt, warm or cold, muddy or clear.

The character of the adjacent land may be indicated by the sediments derived from its waste. The quartz sand and pebbles in coarse sandstones and conglomerates had their source in the older rocks, but in many places have been repeatedly redistributed by streams and concentrated by wave action on beaches. Red shale such as that of the Lobo formation results as a rule from the revival of erosion on a land surface long exposed to rock decay and oxidation, and hence covered by deep residual soil. Limestone, on the other hand, if deposited near the shore, indicates that the land was low and that the streams were too sluggish to carry off coarse material, the sea receiving only fine sediment and matter in solution.

The older formations exposed by the uplifts in Luna County were laid down in seas that covered a large part of the west-central United States, for many of the formations are continuous throughout a vast area. The land surfaces were probably large islands of an archipelago that was in a general way coextensive with the present Rocky Mountain province, but the peripheral shores are not even approximately determined for any one epoch, and the relations of land and sea varied greatly from time to time. The strata brought to view by the uplifts in southwestern New Mexico record many local variations in the geography and topography of the ancient land.

Cambrian submergence.—One of the notable events of early Paleozoic time in North America was the wide expansion of an interior sea over the west-central region. The submergence reached the Rocky Mountain province in the Cambrian period, and for a time a large part of the province remained as land rising above the waters. Its rocks were granites, gneisses, and in some areas sandstones and quartzites of Algonkian age. From the ancient crystalline rocks streams and waves gathered and concentrated sand and pebbles, which were deposited as a widespread sheet of sandstone on sea beaches, partly in shallow waters off shore and partly in estuaries. Abutting against the irregular surface of the crystalline rocks which formed the shore are sediments containing this local material. Subsequently, the altitude being reduced by erosion and the area possibly lessened by submergence, the land yielded the finer-grained mud now represented by the shale in the upper portion of the Cambrian

in some areas. In southern New Mexico and the adjoining regions on the east and west the surface of the crystalline rocks was finally buried beneath the sediments.

Ordovician and Silurian conditions.—The southern New Mexico region was submerged by the sea during parts of Ordovician and Silurian time, and thick deposits of calcium carbonate were laid down. The deposits now form limestones that are prominent members of the stratigraphic series. There were several widespread uplifts of the region during this long period, causing protracted interruption of the sedimentation, and doubtless also the resulting land surfaces were more or less extensively reduced by erosion. The older formations were not deformed, however, and the erosion of the land surfaces progressed in such a way as to produce no marked irregularities in the floor on which the succeeding formation was deposited.

Devonian conditions.—In some portions of the Southwest the Devonian system is represented by extensive deposits of limestone, but in a part of southern New Mexico only black shale appears, and it represents but a small fraction of Devonian time. This meager record is probably due to the fact that during a large part of this period this region was covered by an extensive but shallow sea, or else the land was so low as to leave no noticeable evidence of erosion. On the other hand, it is possible that the sea was so deep and the area so far from shore that it did not receive appreciable deposits. Whether it remained land or sea or alternated from one to the other, the region shows no evidence of having undergone any considerable general uplift or depression until early Carboniferous time. Then there was an extensive subsidence, which established relatively deep-water and marine conditions throughout a large part of the Rocky Mountain province.

Carboniferous sea.—Under the marine conditions of early Carboniferous time calcareous sediments were laid down in southern New Mexico and adjoining regions. They are now represented by several hundred feet of nearly pure limestone known as the Lake Valley limestone. As no coarse deposits of this age occur, it is probable that no crystalline rocks were then exposed above water in this immediate region, although in central New Mexico these rocks rise as a shore cutting off the earlier Carboniferous sediments.

In later Carboniferous (Pennsylvanian) time there were several widespread oscillations of land and sea resulting in alternations of submergence, shore, and land which continued for varying lengths of time and affected somewhat different areas during different portions of the period. Apparently at times the entire Rocky Mountain province was under water and calcium carbonate was deposited in a widespread mantle. In the Deming region the earlier sedi-

ments of the Pennsylvanian series are absent, but the later portion of that epoch is represented by limestones which are thick in the Florida Mountains and lie on an irregular surface that was developed by subaerial erosion. In Cooks Range small amounts of the earlier Pennsylvanian sediments remain. There is uncertainty as to the representation of later deposits of the Carboniferous period, for the age of the Lobo formation is not indicated by any evidence at present available, and in view of the unconformities at the base and top of that formation it is herein tentatively classified as Triassic (?). It is evident that before the deposition of that formation there was uplift with more or less tilting and that great erosion ensued, for an uplifted block along the fault at Capitol Dome was planed off 1,000 feet or more before the deposition of the Lobo.

Early Mesozoic conditions.—As the Triassic and Jurassic periods are not known to be represented in southern New Mexico, it is probable that the area was a land surface for a long time during the early part of the Mesozoic era. As stated above the Lobo formation is tentatively classified as Triassic (?), but it may represent late Carboniferous or even early Cretaceous times. It is probable that some deposits were laid down in the Triassic or Jurassic period, even if they were only the products of streams or lakes and were removed by erosion prior to the Cretaceous period. Aside from some widespread planation there was at this time no notable deformation, and apparently irregularities of land surface, if developed, did not persist.

Cretaceous seas.—During the Cretaceous period a great series of deposits of various kinds but generally uniform throughout wide areas were accumulated over a large part of the western United States. Probably, however, some areas in the central part of the Rocky Mountains were not submerged during this period or were land surfaces during parts of it. The earliest Cretaceous sediments were such as are characteristic of shallow seas and estuaries along a coastal plain. These passed into sediments from marine waters, and these in turn changed toward the end of the period to fresh-water sands and clays with marsh vegetation. Toward the south were open seas in the earlier part of the period in which extensive deposits of calcium carbonate were laid down. In part of southwestern New Mexico a thick body of nearly pure sand was deposited in Comanche time, mainly on the surface of the Lobo formation but possibly overlapping granite in the Pony Hills region. It is now the Sarten sandstone, and although that formation does not crop out in the southern half of the county and in adjoining regions to the southeast and southwest, it was probably deposited over an area of considerable extent. The later Comanche deposits and also the Dakota sandstone appear to be absent, as the Sarten sandstone is suc-

ceeded by the Colorado shale, but without notable evidence of unconformity to represent the long-time interval between them. The shale is a product of marine deposition, which was of great extent in the Rocky Mountains and adjoining provinces. In Luna County only a small thickness of the shale appears, and although later rocks of the Cretaceous period were probably deposited they are buried under the agglomerate or the bolson deposits.

Tertiary deposition, volcanism, and uplift.—The great deposit of agglomerate which occupies so large a part of southwestern New Mexico is believed to have been accumulated chiefly during earlier Tertiary time, although some of the deposits may be of Quaternary age and some may be as old as Cretaceous. The Tertiary was a period of great igneous activity, for at times great sheets of lavas of various kinds were extruded and a vast amount of fragmental volcanic material was poured out. The location of the vents or volcanoes from which these rocks came is not known, but undoubtedly they are represented in part by the stocks and dikes now visible. Igneous rocks were also intruded into the sedimentary strata, mainly the porphyries, which welled up as great laccoliths in the Cooks Range, Fluorite Ridge, and the Tres Hermanas Mountains. Water was an important agency of deposition during the accumulation of the agglomerate, for it includes intercalated beds of water-laid sand, conglomerate, and ash. The great mass of the agglomerate, however, was erupted largely as mud flows and showers of coarse ash and rock fragments. At intervals lavas of several kinds were extruded, andesites and latites first, followed by quartz basalt and rhyolite. The felsitic rhyolite and keratophyre were also extruded, but their relations to the other sheets are not known.

After this epoch there was extensive tilting and faulting of the region, and probably much of the present configuration was outlined. The depressions, filled later with bolson deposits, were excavated and the country was rougher than at present.

Quaternary valley filling.—In Quaternary time the wide depressions received a thick filling of gravel, sand, and clay, borne mainly by streams, which built up the great plain or series of wide bolsons now extending from the Rio Grande to the Continental Divide. This material came from the mountains and ridges, some of it brought from afar. Much of it is fine grained and its thickness is great, showing that a long time was required for its deposition. At intervals there were outflows of basalt as lava sheets on the surface. Later erosion has cut some trenches in the bolson deposits, and the canyons and draws in the mountains and ridges are still being cut deeper. The alluvial fans on the mountain slopes receive more or less detritus from time to time and occasional freshets spread a thin mantle of sand or silt on some of the bolsons. Wind moves some of the loose

materials from place to place and modifies their surface configuration. The wind-blown sand and changes of temperature are powerful agencies in the erosion of the rocks.

MINERAL RESOURCES.

SCOPE OF OBSERVATIONS.

But little study was given to the mineral resources of Luna County, mainly because previous observers have presented accounts of their general features. Descriptions by Lindgren and Gordon [1] and by F. A. Jones [2] have supplied most of the facts in the following pages.

METALS.

COOKS PEAK DISTRICT.

Lead ores carrying silver occur as irregular deposits in the Fusselman limestone in the central and northern portions of Cooks Range. A deposit of silver ore was also mined at the Graphic mine in the agglomerate on the slope east of the range. At present the only production is incidental to prospecting in active progress on a few claims, and the principal output is zinc ore. The original discoveries in the district were made in 1876, but the first openings of importance were made by Taylor and Wheeler in 1880. The total output to the present time has been estimated at about $3,000,000. Of this amount the Desdemona group is credited with $2,000,000, the Graphic group with $450,000, the Summit group with $350,000, and the remaining mines with about $200,000.[3]

The production from 1902 to 1914 is as follows, according to Mineral Resources of the United States, published by the United States Geological Survey:

Production of gold, silver, copper, lead, and zinc in Cooks Peak district, 1902–1914.

Year.	Crude ore.	Gold.	Silver.	Copper.	Lead.	Zinc.	Total value.
	Tons.		*Fine oz.*	*Pounds.*	*Pounds.*	*Pounds.*	
1902	1,778	....	9,275	....	663,300	....	$31,176
1903	2,050	....	5,748	....	1,343,361	....	59,997
1904	1,078	....	4,401	....	576,795	....	27,347
1905	846	....	5,199	....	463,956	....	24,946
1906	1,133	....	7,519	....	627,344	....	40,808
1907	811	....	5,354	....	592,151	....	34,918
1908	253	....	1,009	....	127,535	....	5,891
1909	695	....	4,317	46	597,488	....	27,943
1910	457	....	1,917	47	242,137	....	11,695
1911	45	....	200	....	32,638	....	1,575
1912	927	....	960	....	142,680	433,129	36,897
1913	1,271	....	1,248	1,395	255,901	695,697	51,189
1914	1,995	$68	2,423	2,181	381,324	793,588	56,843

[1] Lindgren, Waldemar, Gordon, C. H., and Graton, L. C., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

[2] Jones, F. A., Mines and minerals of New Mexico, 1904.

[3] Idem, p. 181.

The best-known mines in the district are the Desdemona, Graphic, Poe, Othello, and Monte Cristo and the openings of the Faywood Lead Co. on the west slope of the mountain. The mines are of various kinds, mainly cuts or tunnels, but there are several shafts at Cooks and a deep shaft at the old Graphic mine. The following statements regarding the ores and their occurrence are taken from a report by C. H. Gordon.[1] The ores are mainly lead carbonate with zinc carbonate, galena, sphalerite, limonite, and pyrite, and they occur in the silicified upper part of the limestone (Füsselman) just below the Percha shale. Some of the deposits are under broad arches in the limestone. The ore is in kidneys, pockets, and pipes of irregular shape and varying from some of very small size to valuable bodies. One large chamber in the El Paso was nearly 100 feet long and 35 to 50 feet wide at one place. It yielded about $450,000 worth of ore. Offshoots extending irregularly into the limestone appear to indicate that the ore is a replacement of the limestone, and cross sections of some of these offshoots show a core of unaltered galena surrounded by lead carbonate with a superficial coating of limonite. More or less quartz is associated with the carbonate ore, and although some of the masses are entirely lead carbonate, others have galena, calcite, and some of them fluorite in the center. There are spaces or caves above some of the ore bodies and extending into them, which are usually lined with calcite or quartz or more or less completely filled with clay. In the large ore chamber in the El Paso mine above referred to there was an open space or cave of considerable size above the ore, lined with crystals of calcite and having stalactites of gypsum. The ore deposits are a short distance north of the great mass of porphyry of Cooks Peak, and dikes of porphyry and diabase cut the limestone and overlying Percha shale at several places about Cooks post office. Two dikes of the basic rock 6 feet apart, exposed just west of Coe's house, appear to cut the ore bodies below. It is stated that the space between them was filled with ore and that a body of zinc sulphide occurred in one of them. There is considerable minor faulting in the rocks, and a fault of great amount passes up the main draw at Cooks.

VICTORIO DISTRICT.

The detached hill of limestone at the southeast extremity of the Victorio Mountains has been extensively mineralized with lead ore carrying silver, and several profitable bodies of this ore have been mined. Part of this hill is the Fusselman limestone, of Silurian age, which carries ores in the Cooks Peak and other districts. No igneous rocks appear in the mineralized area of Victorio, but a large sheet of andesite constitutes the main mass of the high ridges a short distance

[1] U. S. Geol. Survey Prof. Paper 68, pp. 288–289, 1910.

to the north, and it may be that this or some underground igneous mass has been a factor in the ore deposition. The structure of the range is shown in figure 9 (p. 84).

Lindgren[1] has reported on the general features of the ore deposits and mining operations at the Victorio camp. He found that the ore bodies were irregular deposits of galena in limestone, in places 20 feet wide, but abruptly thinning to tight seams running northeast. The ore is partly oxidized and accompanied by coarse calcite and siderite or by quartz as a gangue. All the ores contain arsenic. No igneous rocks appear in the outcrop or workings in Mine Hill, but it is suggested that there may be a buried mass to which the ore owes its origin. The ore body crops out only at one point on the west end of the hill, and where it thins out it is represented only by a tight white seam. The main vein so far developed passes through the west end of the hill on a north-northeast course, dipping 60° WNW., but its course is irregular and the ore bodies show variations in attitude. This vein is mostly covered by the Chance and Jessie claims, each of which has produced ore valued at $800,000. The ore body was brecciated material carrying oxidized galena in calcite and locally in quartz gangue. The higher-grade ores, with 15 to 22 per cent of lead, are richer in precious metals, yielding about 50 ounces of silver and 2 ounces of gold to the ton. The ore continued for about 1,000 feet along the vein and was mainly above a tunnel that followed the vein from a crosscut in the northwest slope of the hill. Some years later an additional ore body was discovered near the main vein and yielded nearly $100,000, and other bodies were developed to some extent on the southwest end of the hill. Similar ore-bearing fissures were found in the limestone in other portions of the hill, but they have not yet proved profitable.

A vein of quartz carrying wolframite traverses the Montoya limestone on the south slope of the hills about half a mile west of the mining camp. The vein trends S. 5° W. and dips 70° S. 85° E., or about at right angles to the dip of the limestone. Its width ranges from 8 inches to 2½ feet, and the mineral is in black masses scattered irregularly through parts of the quartz. There are also small amounts of pyrite, galena, wulfenite, and probably also scheelite, and the quartz is reported to carry a little gold. The production of wolframite so far has been about 14 tons of closely cobbed mineral, leaving very little of it remaining in sight. The principal operations in the Victorio camp were in 1880 to 1886 and again in 1909 and 1910, when small shipments were made from the Helen, Last Chance, and Rambler mines. In 1912 and 1913 mining was in active operation on a small scale and considerable high-grade ore was produced.

[1] Op. cit., pp. 290–292.

TRES HERMANAS MOUNTAINS.

For many years ores of various kinds have been known to exist in the Tres Hermanas Mountains, and at times there has been a small production which appears to have afforded some profit. The only mining in progress in 1912 was in a small lead in the central part of the mountains, where a little silver-bearing galena was produced by two workmen. Zinc ores in the Tres Hermanas Mountains have been described in considerable detail by Lindgren,[1] and the following facts are taken from his descriptions. The openings are a series of small pits in the north-central margin of the district near the base of the hills, about a mile west of the north peak. The ore was discovered in 1904, and several shipments were made in 1905. The ore is in limestone of Carboniferous age that lies near the great mass of porphyry and is penetrated by offshoots from that mass. This limestone contains bunches of wollastonite in the area yielding zinc. The zinc deposits are in irregular bodies and were opened originally for galena, which occurred in small amount at the surface. The galena was worked to some extent, but there was difficulty in obtaining ore of sufficiently high grade to repay the cost of the long wagon haul to the railroad and shipment to smelters.

The zinc ore consists of oxidized zinc minerals and some galena, in part interbedded in the limestone and in part in short, ill-defined, nearly perpendicular fissures and veins cutting across the beds and varying in strike from northwest to southwest. In places it also forms irregular bunches in the limestone. In one locality on the south slope of the limestone hill the oxidized zinc ores occur in kidneys and bunches between beds of coarse crystalline limestone and garnet rock. A veinlike deposit striking N. 60° E. and standing nearly vertical also contains zinc ore at this place.

Much ore occurs in altered limestone near the igneous contact. At the principal workings part of the ore is interbedded with the limestone and part occurs along a vein with west-northwest strike. The ore grades into limestone and has to be carefully picked.

Lindgren suggests that systematic prospecting with drills might reveal deposits interbedded among the altered limestone strata. The ore is in dark-gray cellular masses, consisting largely of the very unusual anhydrous silicate willemite. The willemite forms small radial aggregates of slender hexagonal prisms terminated by a flat rhombohedron and is accompanied by small amounts of a dark material which looks like pyrolusite and gives a dark tint to the ore. It also forms loose crystalline aggregates and crusts of needle-like crystals. Smithsonite, or zinc carbonate, of light-gray color and mammillary form is also present. Hydrozincite occurs as an in-

[1] Lindgren, Waldemar, The Tres Hermanas mining district, N. Mex.: U. S. Geol. Survey Bull. 380, pp. 123–128, 1909; The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 292, 1910.

crustation, and tabular crystals of calamine were noted in crevices of the ore. The galena seen at the principal workings is accompanied by a little pyrite and is intimately intergrown with wollastonite in a manner indicating contemporaneous deposition. The ores shipped from these mines probably contained about 30 per cent of zinc. Shipments of lead-zinc ores are stated to have contained from 11 to 40 per cent of lead and 2 ounces of silver to the ton, also as much as 19 per cent of zinc and 4 per cent of lime, 4.2 per cent of iron, and 7.4 per cent of silica.

Several ore-bearing veins occur in the rhyolite on the west side of the Tres Hermanas igneous mass, notably one which has been worked in the Cincinnati, Hancock, Yellow Jacket, and Alexander mines. This lode has a west-southwest course and is traceable for about a mile, or to a point about 1½ miles south of the zinc mines. The Cincinnati mine is reported to have produced $100,000 from ore rich in lead and gold. At the Hancock mine the vein is said to be 8 inches wide in places. There is a 400-foot shaft at this mine, which is largely in a body of quartz diorite, cutting or underlying the rhyolite. This mine is reported to have produced 1,000 tons of rich lead ore carrying some gold. The only mine in operation on this lode in 1912 was the Alexander, where two men were obtaining a small amount of galena carrying silver. This mine is near the contact of the rhyolite with a mass of limestone which lies along the main porphyry contact. A few small prospects have been reported in the main mass of the porphyry, but they have not as yet proved valuable. One a short distance south of the zinc mines disclosed some copper ore.

CARRIZALILLO HILLS.

The igneous rocks of the Carrizalillo Hills have been prospected at many points and evidently yielded some mineral, but not in paying quantity. A vein recently opened high in the slopes half a mile south-southwest of Hermanas station shows considerable rich copper ore containing gold, of which a small shipment has been made.

SIERRA RICA.

Considerable mining and prospecting have been done in the northern extension of the Sierra Rica, in the extreme southwest corner of Luna County. The principal claim, known as the International mine, is situated a short distance from the boundary line, at a point about half a mile west of boundary post 38. The following facts regarding this mine are taken from notes by J. M. Hill.[1] Operations

[1] U. S. Geol. Survey Prof. Paper 68, pp. 346–347, 1910.

were begun by Volney Rector in 1880, and it is reported that 50 tons of lead-silver ore was produced, which was valued at $25 a ton. The best material obtained, a 10-ton shipment, contained 40 per cent of lead and 65 ounces of silver to the ton. In 1909 there was about 80 tons of galena ore of medium grade on the dump, and as much more in one of the stopes. The ore occurs in a vein of banded quartz from 2 to 10 feet wide, averaging about 3 feet, occupying a fault that trends N. 30° E. and stands nearly vertical. It traverses limestone dipping 30°–40° NW. On the south side is massive red limestone; on the north or hanging-wall side there are thin gray to buff beds, separated from the vein by coarser red grit, with grains showing silica enlargement. The vein is traceable for nearly a mile, its south end being in Mexico, and it has been prospected by numerous pits. The ore from stopes near the Mexico line consists of malachite, azurite, some cerusite, and a few nodules of chalcopyrite and galena, in a limonitic quartz gangue. Some of this ore is reported to assay 10 per cent of copper and 60 ounces of silver to the ton. About 500 feet farther north a 150-foot shaft found good galena ore in the upper levels, but at a lower depth the vein was barren quartz. In a 50-foot shaft 250 feet still farther north there is a drift extending southwest 60 feet along the vein. It found in the hanging wall limonitic quartz, with a little galena and considerable silver, probably as chloride and in cerusite, and in the footwall 2 or 3 feet of massive galena ore, reported to carry about $35 a ton in lead and silver.

FLORIDA MOUNTAINS.

Many claims have been located in the Florida Mountains, but only a few of them have shown sufficient mineral to be of any importance. The principal ores observed have been silver-bearing galena and zinc ores in the limestone. Several small mines have been developed, and from time to time have produced sufficient ore for shipment; but of late only two mines are in operation. One known as the Silver Cave is on the limestone high on the southeast slope of Gym Peak. It is reported to have yielded $60,000 worth of ore in 1905. The workings consist of a drift and several small stopes. The ore is silver-bearing galena and occurs as a replacement of the limestone. Just west of Gym Peak, at the Mahoney mine, are a number of pits and drifts in the limestone, following a series of small irregular masses of oxidized zinc ore. Similar ore has also been mined in small amount from the limestone on the west slope of Capitol Dome. Several small leads of copper ore have been worked in the granite in claims along the west slope of the mountains, and small shipments of ore were made from two localities. The ore consists of chalcopyrite and other copper sulphides impregnating the granite along joints and

zones in which the rock is considerably shattered. The bodies, so far as known, are small and irregular. A short distance south of Capitol Dome[1] there is a vein trending N. 62° E. and dipping 80° SE. Two tunnels, one 280 feet long and a lower one 420 feet long, have been driven. A 100-foot shaft 40 feet above the upper tunnel connects with the lower tunnel by a raise. These workings have long been abandoned.

FLUORITE.

The following statements are condensed from a detailed account of the fluorite deposits:[2]

From the southeast end of Fluorite Ridge there was mined in 1909 to 1911 about 9,000 tons of fluorite. This mineral consists of calcium fluorite, with a small amount of impurities, and is in considerable demand in the manufacture of open-hearth steel and for several other purposes. The fluorite of Fluorite Ridge occurs in steeply dipping veins, mostly in the porphyry, and ordinarily it is of exceptionally good quality. The veins range from a few inches to 12 feet or more in thickness, but the general range in the workings is from 2 to 5 feet. They extend along planes of fracture of the rock, some of which are slightly faulted. One set of veins strikes N. 17°–27° E. and another set N. 6° E. to N. 18° W., but others strike at various angles between N. 17° E. and N. 18° W. There are three principal areas—one at Fluorite Camp, a second a quarter of a mile or more to the northeast, and the third about a mile northwest of the camp. In 1912 a mine was opened still farther west.

The opening at the camp is in porphyry near the fault plane which passes along the east side of the limestone ridge and separates the Ordovician limestones from an extension of the main porphyry mass. In the largest pits the vein has been worked to a depth of 80 feet and for a distance of about 100 feet along its north-northeast course. This vein dips 65°–70° SE. and ranges in thickness from 4 to 12 feet. Other veins have been opened to some extent at several points in the immediate vicinity.

At the openings northeast of the camp the fluorite vein appears to be along a fault plane with agglomerate on the east side and chert on the west side. The deepest workings reach a depth of 75 feet and the vein ranges in thickness from 1 to 8 feet. Its course is S. 10° W., and it stands nearly vertical. There are several minor twists in it and indications of some faulting, notably in the occurrence of slickensided surfaces.

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[1] U. S. Geol. Survey Prof. Paper 68, pp. 289–290, 1910.

[2] Darton, N. H., and Burchard, E. F., Fluorspar near Deming, N. Mex.: U. S. Geol. Survey Bull. 470, pp. 533–545, 1911.

Two veins of fluorite have been opened but not worked in the locality a mile northwest of the camp. They are in the porphyry not far below the overlying sandstone and stand nearly vertical. One vein ranges from 1 foot to 4 feet in thickness and the other averages about 1 foot, but the mineral is not all pure.

Some analyses of carload lots of fluorite from Fluorite Ridge made by the Colorado Fuel & Iron Co. showed a variation from 88.3 to nearly 94 per cent of CaF_2, with an average of 92 per cent. The principal impurity, silica, ranged from 3.84 to 9.85 per cent, iron oxide and alumina from 0.68 to 1.12 per cent, and calcium carbonate from 0.48 to 1.12 per cent, the latter quantity being in the fluorite which contained 94 per cent CaF_2. Compared with fluorite from Colorado, Kentucky, Illinois, and other places the Fluorite Ridge mineral averaged much higher in grade, notwithstanding the fact that it had not been washed.

MARBLE.

Some of the gray limestones of this region are suitable for use as marble, and true crystalline limestone has been found at a number of localities. The most notable occurrence of such limestone is on the south side of the southern one of the high peaks at the north end of the Tres Hermanas Mountains. There is a body of considerable size at this place, lying against the porphyry and evidently a wedge of Gym limestone altered by the heat of the igneous intrusion. Much of the rock is of a pure white color and a coarsely crystalline texture and is well suited for decorative purposes. It is considerably fissured so far as exposed. Similar marble occurs along the igneous contact at the zinc mines on the northwest slope of the same range, but it is not very attractive in appearance and is very irregular in character and structure.

In the Victorio Mountains, a short distance northwest of the mining camp, is a body of fine-grained pure white marble, but it appears not to be large. Doubtless it has been altered by igneous intrusions, but none of the igneous rock appears at the surface at this point, although there are large dikes a short distance to the west.

Marble deposits are of no economic value unless they are so situated that the rock may be quarried and transported economically, and they should be large, free from serious shattering, and yield a product of attractive appearance. Uniformity of texture and tint are requisite features.

ONYX.

Deposits of onyx occupy fissures in the agglomerate at a number of places, and some small masses have been uncovered, one of them in the southwest slope of the agglomerate ridge 3 miles northwest of

Mirage. The color is nearly white and the texture somewhat uneven, and the bodies appear not to be sufficiently large to be of economic importance. There are onyx claims on the slopes 4 miles west of Columbus which have yielded some very good samples, but the extent of the deposits was not ascertained.

BUILDING STONE.

Many of the rocks in the ridges about Deming are suitable for building stones, and some of them would be of considerable value for that purpose if they were nearer to market. The granite and some of the other igneous rocks would dress and polish satisfactorily, and there are sandstones of several varieties. Some of the limestone could be used for gray marble. The only developments are two quarries, one in the Sarten sandstone on the main road a mile south of Fryingpan Spring and the other in the tuff of the Florida Mountains 2 miles northeast of Arco del Diablo. The sandstone is nearly white in color and is easily worked in blocks of good dimensions. The quarry was opened to supply material for the new county courthouse at Deming. The quarry in tuff is a small one, but has exposed a large quantity of excellent gray freestone in massive beds. The color is bright, and although there is some slight mottling by darker-gray fragments the general effect is good.

LIMESTONE.

Limestone suitable for burning into lime or for the manufacture of Portland cement is abundant in the limestone areas of the Florida Mountains, Fluorite Ridge, and the Snake Hills. Considerable portions of the El Paso, Gym, and Lake Valley limestones and some of the Montoya limestone that does not contain chert are sufficiently pure for these purposes, but there is at present no disposition to utilize them.

BRICK CLAY.

Portions of the bolson deposits are loamy mixtures of clay and fine sand suitable for making common brick, and a small number of brick have been made. The principal use of the material, however, has been for the larger unburned brick known as adobe, which have been extensively used for building in Deming and at ranches in the surrounding country.

ROAD METAL.

Rocks of various kinds which could be crushed for road metal are available in endless supply in the ridges, but so far they have not been utilized. The caliche, a mixture of sand and calcium that lies short distance below the surface in many places, has been employed

for surfacing the main road north of Deming, and the excellent results obtained should be an encouragement to extend the treatment over other roads.

GUANO.

Considerable bat guano was found in the large pit in the marble on the east slope of the south peak of the Tres Hermanas Mountains. A trail was built up the steep slope and an incline placed in the pit for the removal of this material, and several tons of it was taken out for use as fertilizer.

GARNET.

The yellowish garnet occurring along the contact of marble and porphyry at the pit just described is sufficiently hard to use as an abrasive. This material is extensively mined at some places in the United States, and when of satisfactory quality its average value is $30 a ton.

WATER RESOURCES.

STREAMS.

The streams in Luna County flow only during times of freshet, and these are of short duration. Often in the spring or early in the summer Mimbres River has a flood of such volume that the water is 10 to 15 feet deep and overflows the lower lands adjoining its channel. This condition may last a few days and recur two or three times in a season. In some years the maximum stage of the river is a very small flow, not reaching far beyond Deming, but occasionally it extends into the wide valley east of the Florida Mountains as far as T. 25 S., where it widens into a shallow lake. From December, 1904, to May. 1905, and again in January to April, 1906, the Mimbres flowed nearly to the Mexico boundary for the only time in 18 years. In Recent geologic time, however, it flowed through this valley and out into the Palomas Lakes and other basins in Mexico. At no distant time, also, it flowed through the wide bolson west of the Florida Mountains and found an outlet through the low pass between that range and the Tres Hermanas Mountains.

In April, 1908, a gaging station was established on Mimbres River just below the Rio Mimbres dam site, in sec. 7, T. 20 S., R. 10 W., about 6 miles southeast of Faywood Springs and about 10 miles northeast of Faywood station, on the Silver City branch of the Santa Fe Railway. Gage-height records and discharge measurements have been obtained since 1908. The channel at the station is very shifting in character, and numerous measurements are necessary to obtain the best results. For this reason the results recorded and the estimates of flow for periods between measurements and at

high stages are only approximate. The following table shows the monthly run-off in acre-feet:

Monthly run-off, in acre-feet, of Mimbres River east of Faywood, N. Mex.

Month.	1908	1909	1910	1912	1913	1914
January	....	1,060	314	....	793	1,190
February	....	530	245	....	142	334
March	....	548	144	....	468	243
April	....	187	131	....	3,400	236
May	713	136	111	553	247	228
June	577	74	147	482	202	655
July	7,750	364	304	2,190	193	....
August	7,620	701	1,650	2,640	548	5,300
September	3,750	212	155	2,150	352	1,590
October	3,090	275	0	707	133	3,890
November	1,420	411	10	655	464	1,300
December	1,860	139	0	615	1,270	12,300
	26,800	4,640	3,270	9,990	8,210	....

NOTE.—Owing to the shifting character of the stream bed and the few discharge measurements, no estimates of flow can be made for 1911. Gage out of order May 11-16, 24-30, July 21-25, and Aug. 12-15, 1914.

The maximum daily flow, from 1908 to 1913, was in August, 1908, when two days are estimated at 910 and 1,000 second-feet, respectively. Probably this was exceeded in the great flood of July 18 to 24, 1914, but unfortunately the volume of this was not determined owing to a mishap to the gage. There was also a notable flood from December 22 to 25, 1914, with flows of 1,420, 1,270, 970, and 580 second-feet. Other notable flows were 61 second-feet for 14 days in October, 1908, 93 second-feet July 13, 1909, 108 second-feet August 14 and 15, 1909; 196 second-feet August 10, 1910.[1] The mean yearly flows for 1909, 1910, and 1913 are 6.4, 4.5, and 8.6 second-feet, respectively. The ordinary flow is between 1 and 8 second-feet, but this small amount is due to the fact that much of the water is drawn off for irrigation above the gaging station. Accordingly, most of the figures given above represent flood conditions and the total amount of normal flow is not indicated.

After rainy periods the water of the Mimbres frequently flows down the valley as far as Taylor Mountain, in T. 20 S., or to and beyond Spalding. Its main branch, the San Vicente Arroyo, is also subject to frequent floods in which the water flows as far as its mouth. Streams flowing out of Cooks Range are occasionally filled with water by a succession of heavy storms, but their flow is short-lived and rarely reaches the Mimbres. The same is true of Palomas Arroyo, which has a large drainage basin in the bolson, but ordinarily the flood waters even of cloud-bursts mostly sink in the porous bolson soil.

[1] Territorial Engineer Second Bien. Rept. to Governor of New Mexico, 1905–1910, Santa Fe, 1911.

SPRINGS.

There are few springs with large discharge in Luna County, and even seeps are not common in the rocks of the ridges. The largest spring is on the Butterfield road just west of Fort Cummings. It was cleared out by the Government when the fort was established and made into a curbed well 15 feet in diameter protected by a roofed house, shown in Plate V, *A* (p. 13). Now the water is piped to Florida station for use by the railway company. This spring is largely due to a rock dam of rhyolite which crosses the small arroyo. Its underground source is not known, and it may either come out of sedimentary deposits covered by basalt or rise from the agglomerate which doubtless lies not far below.

A notable spring rises in the arroyo a mile below Cooks post office, and the water from it usually flows for a short distance. Its source is in the Sarten sandstone. Another spring rises from the sandstone in this same hollow at the fault a mile farther southeast. Several springs and seeps occur in canyons in the Cooks Peak area, but their volume is small.

A well-known stock-watering place called Cow Spring is in the northern part of T. 22 S., R. 13 W. It yields a large amount of water, and the supply is stated not to vary greatly in volume. The spring appears to be caused by a rock dam raising the underflow in the valley, which has a small drainage basin to the northwest. The rock does not reach the surface at the spring, but rises in ridges to the south and northwest.

Carrizalillo Spring rises from the bottom of a small valley a short distance west of Hermanas and is caused by a rock dam which crops out near by. The spring is a large one and its water has been utilized for stock for many years. Part of it is now piped to Hermanas for use by the railroad. Since it has been pumped the water level has been lowered so that it is now 3 feet below the surface. An analysis of the water is given on page 125.

Niggerhead Spring is a seep flowing out of the joints of igneous rocks in the Tres Hermanas Mountains. It was a favorite camping place for the Apache Indians and later for the soldiers who came to drive these Indians out of the country.

Willow Spring is a water hole in the agglomerate on the southeast side of the Tres Hermanas Mountains. Now it is used as a well for windmill pumping by a Mexican who has a ranch there.

In the slopes of the Florida Mountains there are several small seeps and springs which are used as watering places for goats and cattle. Byer Spring, 3 miles southeast of Arco del Diablo, is the best known of these, but its volume is very small.

Fryingpan Spring rises along the great fault 2½ miles west by south of Fort Cummings. It has a small flow which runs down the draw a few rods and supplies cattle in the adjoining range.

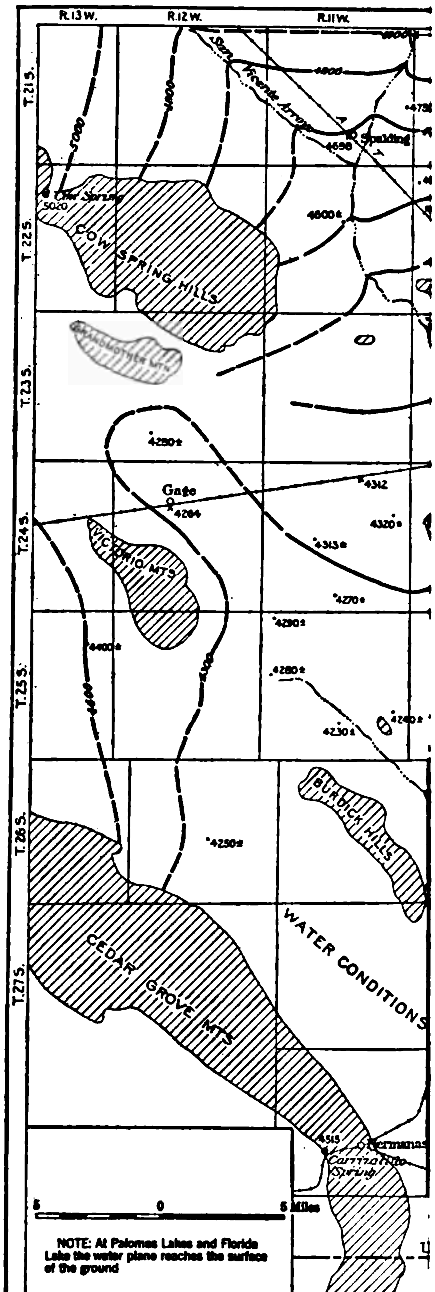
Puma Spring is a small one rising from the agglomerate a mile northwest of the Wilson ranch northeast of Fluorite Camp. It is dug out as a well and is not in use at present.

UNDERGROUND WATER.

GENERAL CONDITIONS.

The thick body of sand and gravel underlying the wide bolsons of Luna County contains a very large volume of water, most of which is within 25 to 150 feet of the surface. The local conditions as to depth and volume of water vary from place to place, but there are extensive districts in which the depth probably is not too great for profitable pumping and the volume is ample for the irrigation of large areas. Numerous wells have been sunk which indicate the water resources in many places, but in some sections little information is available. One of the principal objects of the investigation here reported was to collect all the available facts that would throw light on the limits of the water-bearing areas and on the thickness, depth, and water-bearing capacity of the different strata. It is a popular belief that the water is a wide extension of the underflow from Mimbres River, but, while the stream had originally much to do with the deposition of the water-bearing materials, it does not furnish much of the water. There are wide areas in some of the bolsons in which water is not available or lies too deep to be of service for irrigation, and these are in some measure delimited on the map (Pl. I, in pocket). A district containing shallow underground waters in good volume lies about Deming and in the wide bolson extending southward from that place on the west side of the Florida Mountains. In the great valley on the east side of these mountains the conditions are unfavorable, for south of T. 24 S. there is barely sufficient water for stock. Another district in which underground waters are available lies along the valley of Palomas Arroyo from Iola to and below Columbus. In the following pages there is given a list of wells and descriptions of the local conditions. In Plate VIII are shown the form and elevation of the water surface, based on heights of water in representative wells tied to the best available data as to land elevations. The contour lines show the elevations of the water surface above sea level. Plate IX (p. 116) shows some of the underground water conditions about Deming and is based on well records and other data supplied by Mr. R. H. Case, of Deming.

U. S. GEOLOGICAL SURVEY



Altitude of water surface above sea level
Shown by contour lines with 100 feet vertical interval. Broken lines approximate

×4106

Determined altitude of water surface in

MAP SHOWING GRADE OF UNI

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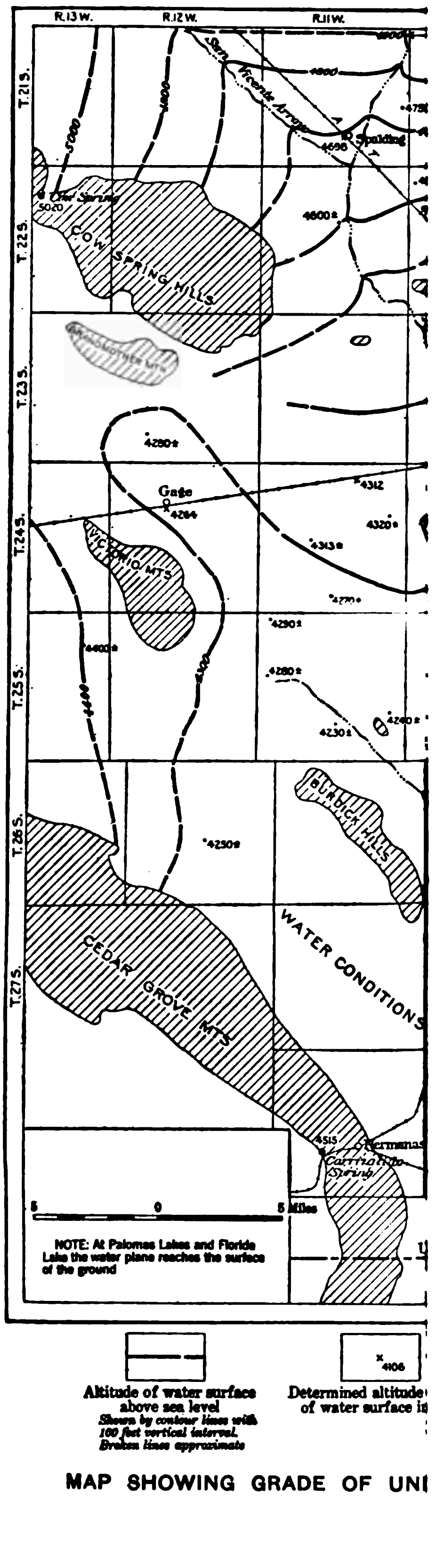


MAP SHOWING GRADE OF UN

EXTENT OF THE WATER-BEARING STRATA.

By far the largest volume of water in Luna County underlies the broad bolson extending southward from Deming to the foot of the Tres Hermanas Mountains and thence southeastward through the gap between that range and the Florida Mountains to the Palomas Lakes. Most of the wells in T. 24 S., Rs. 8 and 9 W.; T. 25 S., R. 9 W.; and T. 26 S., Rs. 9 and 10 W., and the valley of Palomas Arroyo found a large supply of water at depths of 50 to 200 feet that rises within 20 to 60 feet of the surface. The limits of the district in which this favorable condition exists are of great practical importance to settlers, for outside of the area underlain by an adequate water supply the land is of but little value for agriculture. Unfortunately, without records from many wells, the underground conditions in the bolson deposits are difficult to trace and the limits of the water-bearing strata can not be located with precision. The Florida Mountains and other ridges delimit the area in places, but the form of the bedrock floor under the bolson deposits is not indicated. Doubtless also there are many small ridges of rock underground similar to those appearing in the Snake Hills and Midway Buttes as well as many other projections which are not sufficiently high to rise above the bolson but which approach so near to the surface as to cut off the underflow. On the map (Pl. I, in pocket) the underground-water conditions are set forth so far as information concerning them is available. Undoubtedly a large part of the area shown on this map with the symbol for "water conditions not determined" is barren of serviceable underground supplies, and most parts of the areas in which water is more than 60 feet below the surface do not contain water in large volume. The broad basin south of the Cedar Grove Mountains contains but little water, and the great sink of the Mimbres east of the Florida Mountains appears to have but a scanty water supply. In the district lying between Cooks Range and the Goodsight Mountains the conditions appear to be more favorable, but they have not been adequately tested. Probably there the water surface is considerably deeper than in the Deming region.

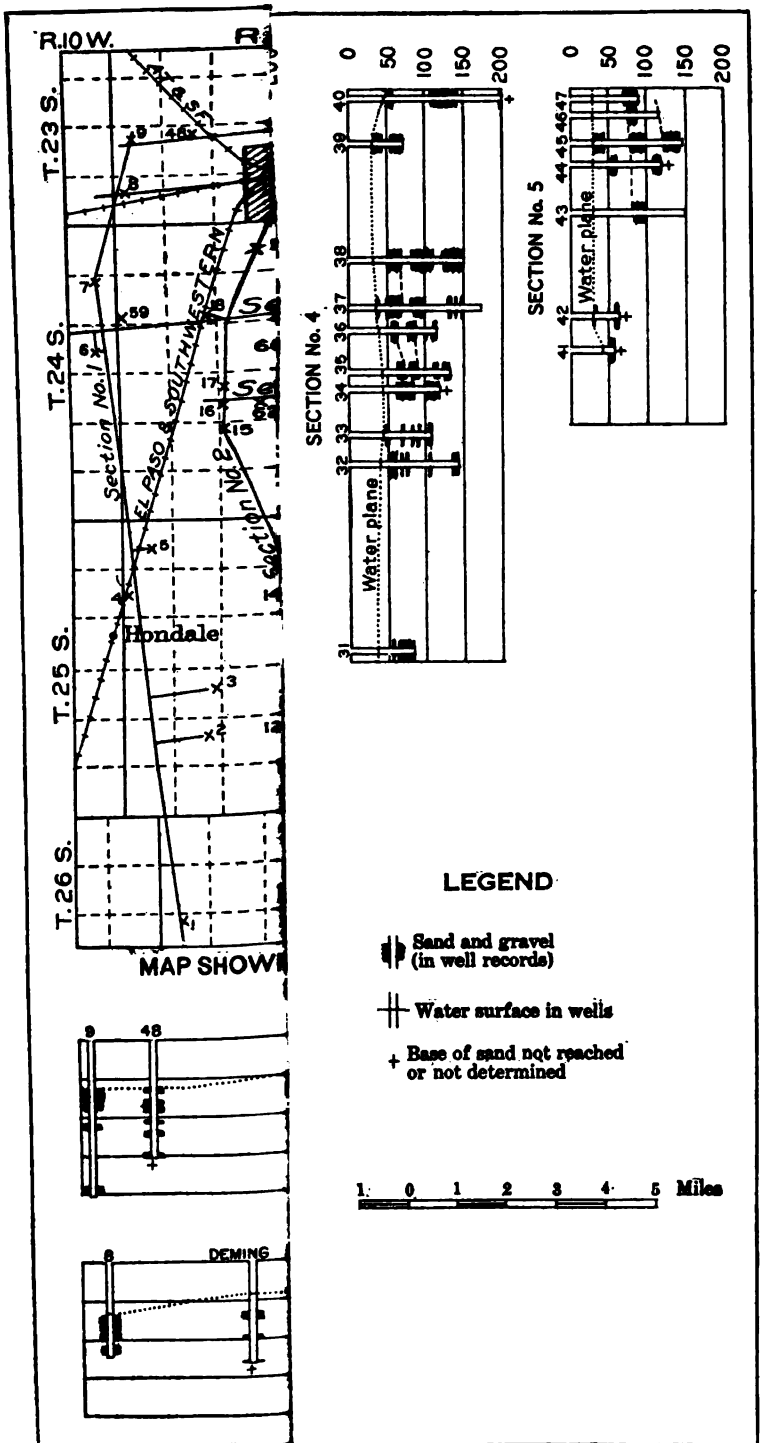
SOURCE OF THE UNDERGROUND WATER.

Much of the water contained in sand and gravel under the great bolsons of Luna County is derived from local rainfall. This amounts to about 10 inches a year (see p. 16), and though most of the water evaporates a considerable proportion passes underground. Mimbres River brings a certain amount of water into the region, and the flow which it gathers from the mountains on the north has been passing

underground for a very long time and gradually adding to the bulk of water in the coarser beds underlying the wide bolsons about Deming and farther south.

There is no run-off in the bolson except after cloud-bursts, when small amounts of water may flow to the lower ground, where it either evaporates or sinks. On the mountain slopes there is considerable run-off which flows out upon the bolsons. Owing to lack of knowledge as to the proportion of rainfall which passes underground in the region, it is not possible to give figures as to the rate at which the underground water accumulates in the bolson deposits. The loss by evaporation is very great, especially in some deeper portions of the bolsons, where there are at times accumulations of run-off water, and in areas where thick deposits of relatively impervious clay hold the water at the surface. Capillary action in soils and subsoils, which is especially strong in arid regions, adds greatly to the depletion of the water absorbed by the soil from rainfall, for this agency returns much of it to the surface, where it is lost by evaporation. The extent of this action is well illustrated in this region by the great accumulation of caliche, which is calcium carbonate that was brought up by capillary movement of the underground water.

The only notable sources of underground-water supply entering the county are the underflows of Mimbres River and Arroyo San Vicente. It has been estimated by engineers of the Mimbres Dam Co. that Mimbres River above the dam site in sec. 6, T. 20 S., R. 10 W., has a catchment area of about 600 square miles. One quarter of this is in mountains, where the total annual precipitation is about 20 inches. one-half is a high area having a precipitation of about 15 inches, and the remainder is made up of foothills in which the precipitation is about 12 inches. In all, this gives an annual rainfall of nearly 500,000 acre-feet of water, but evidently there is great loss by evaporation and other causes, for the surface flow gaged since 1908 at the dam site shows only about 3,270 to 30,000 acre-feet a year with an average near 10,000 feet, and the additional underflow at that place is estimated at 2,000 acre-feet a year. As this water is not held by a dam at present, considerable of it passes down in floods, and when the stream overflows on the low lands adjoining the channel a fairly large proportion is lost by evaporation. When it is held by the dam it will not be free to pass underground until it has done duty in irrigation, which will greatly increase the loss by evaporation and correspondingly diminish the volume of underflow. Assuming that all the 12,000 acre-feet of water passes underground and extends under the 14 townships contiguous to the line of its southward flow to Palomas Lakes along a course west of the Florida Mountains would give an annual increment of less than half an inch a year under that area.


R.10 W.
T.23 S.
T.24 S.
T.25 S.
T.26 S.
A.T.& S.F.
EL PASO & SOUTHWESTERN
Section No.1
Section No.2
Hondale
MAP SHOW
DEMING
SECTION No. 4
SECTION No. 5
Water plane
LEGEND
Sand and gravel (in well records)
Water surface in wells
Base of sand not reached or not determined
1 0 1 2 3 4 5 Miles

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THICKNESS OF WATER-BEARING BEDS.

The deposits that underlie the bolsons of Luna County vary greatly in their capacity to hold water, not only from bed to bed but in the same bed from place to place. There are many deposits of sand, and some of the well records show that these attain a thickness of 40 to 50 feet. In most places, however, the thickness is much less, and many of the borings show more or less admixture of clay. The thickness and relations of the principal water-bearing beds of the Deming region are shown in Plate IX.

Some representative sections are given in the following paragraphs to show the thickness of the water-bearing beds in various parts of Luna County.

In T. 23 S., R. 7 W., the water-bearing sands show much variation in thickness. A 195-foot well in the SW. ¼ sec. 21 has sands at 74–87, 89–117, and 177–195 feet, or 59 feet in all. A 147-foot well in the NW. ¼ sec. 19 has sands at 70–78, 102–108, and 130–147 feet, or 31 feet in all. Wells from 90 to 100 feet deep in the southeastern part of the township have from 8 to 23 feet of sand. A 101-foot well in the SW. ¼ sec. 30 has sands at 22–24, 29–35, and 64–101 feet, or 45 feet in all, but a 90-foot well in the NW. ¼ of this section had only 23 feet, the lower sand member containing beds of fine-grained material. A 290-foot boring in the NW. ¼ sec. 12 penetrated several sand beds, apparently more than 50 feet in all.

In the southern half of T. 23 S., R. 8 W., the sand deposits are thick and carry a large volume of water. A 200-foot well in the SW. ¼ sec. 18 has sands at 51–59, 110–141, and 197–200 feet, or 42 feet in all, and a 72-foot well in the SW. ¼ sec. 19 has 31 feet. A 115-foot well in the NW. ¼ sec. 23 has sands at 45–50, 56–60, 66–80, and 88–92 feet, or 27 feet in all, and a group of wells from 92 to 103 feet deep in secs. 25, 26, and 27 find from 37 to 44 feet of sand. A 143-foot well in the NE. ¼ sec. 28 has sands at 34–60, 66–83, 112–118, and 136–143 feet, or 57 feet in all, and a 156-foot well in the SW. ¼ sec. 32 has the same amount in beds at 29–45, 80–104, and 140–156 feet. That the sands thin somewhat to the south is shown by the record of a 105-foot well in the SW. ¼ sec. 12, which has sands at 65–72, 80–81, 83–85, 88–92, and 98–105 feet—only 21 feet in all.

In the township in which Deming is situated (T. 23 S., R. 9 W.) records are available for 11 wells more than 100 feet deep, mostly in the southern tiers of sections. A 143-foot well in the SW. ¼ sec. 25 has sands at 44–62, 66–78, 85–100, and 122–134 feet, or 58 feet in all, but another well of similar depth in the same quarter section has only 36 feet, the second and fourth strata not being represented. A 164-foot well in the SE. ¼ sec. 26 has sands at 40–58, 74–80, 86–90, and 145–160 feet, or 43 feet in all, and a 142-foot well in the center

of this section has a similar amount. A 160-foot boring in the NW. ¼, however, has sands at 40–50, 73–80, 88–90, and 145–160 feet, or only 34 feet in all. A 160-foot well in the SE. ¼ sec. 27 has sands at 47–55, 84–105, 125–129, 140–145, and 150–158 feet, or 41 feet in all. A 150-foot boring in the NE. ¼ sec. 29 has sands at 61–68, 75–90, 102–108, 115–125, and 148–154 feet, or 42 feet in all. A 203-foot boring in the NW. ¼ sec. 30 has sands at 65–83, 109–112, and 190–200 feet, or 31 feet in all, and a 120-foot well a mile farther south has sands at 65–96 and 105–114 feet, or 40 feet in all. A 215-foot well 3 miles northeast of Deming has seven thin beds of sand at intervals, or 19 feet in all, and some of the sand is very fine grained.

In the northwestern part of T. 24 S., R. 8 W., there are several 150-foot wells which penetrated more than 50 feet of water-bearing sands. One in the NW. ¼ sec. 7 reports water-bearing sand from 46 to 100 feet; one in the NW. ¼ sec. 6 has sands at 50–70, 85–110, and 122–147 feet, or 70 feet in all; and a 114-foot well in the northwest corner of sec. 5 has sands at 54–65 and 104–114 feet, or only 21 feet in all. In the northwest corner of sec. 21 a 510-foot boring has sands at 32–38, 60–65, 265–270, 319–325, and 502–508 feet, only 28 feet in all, and a deep well in the SE. ¼ sec. 20 has only 35 feet. A 161-foot test boring in the NW. ¼ sec. 30 has sands at 45–50 feet and at intervals from 67 to 96 feet, with clay below, aggregating only about 20 feet of sand.

In T. 24 S., R. 9 W., the next township west, there are many records showing considerable diversity in the strata. An 80-foot well in sec. 4 and a 133-foot well in the SE. ¼ sec. 8 have 28 feet of sand each. Two wells, 115 and 123 feet deep, in the southern part of sec. 12 have 24 and 26 feet of sand in beds mostly from 6 to 9 feet thick. A 128-foot well in the NE. ¼ sec. 13 has sands at 58–68, 78–86, 105–114, and 118–125 feet, or 34 feet in all, and a 115-foot well in the SW. ¼ of this section has 35 feet in two beds. A 150-foot well in the NW. ¼ sec. 13 has only 14 feet of sand in its second, third, and fourth strata. A 145-foot well in the NW. ¼ sec. 14 has sands at 48–53, 65–72, 102–112, 125–129, and 133–138 feet, or 31 feet in all. A 100-foot well in the SW. ¼ sec. 15 has 10 feet of sand, mostly at the bottom. A 177-foot well in the NW. ¼ sec. 21 has sands at 63–70, 83–88, and 165–177 feet, or 24 feet in all, and another well in the SW. ¼ of this section has sands at 56–68, 124–134, and 152–158, or 28 feet in all, respectively. Two wells in sec. 23, 79 and 83 feet deep, have 27 and 29 feet of sand. A 110-foot well in the SE. ¼ sec. 24 has five sands 4 to 5 feet thick, or 22 feet in all; and beds of similar character and the same aggregate thickness are found in a 145-foot well in the NE. ¼ sec. 25. In the NW. ¼ sec. 28 a 203-foot well penetrated sands at 53–75, 130–132, 158–162, and 180–182 feet, or 30 feet in all.

In T. 24 S., R. 10 W., the sands are of irregular extent and thickness, owing in part to their interruption by Red Mountain and the Snake Hills, but in the eastern part of the township conditions are the same as in adjoining townships on that side. A 135-foot well in the NE. ¼ sec. 12 has sands at 64–90, 103–106, 115–118, and 127–130 feet, or 35 feet in all, but a 208-foot well in the SE. ¼ sec. 13 found the top sand much thinner and a 7-foot bed of sand at the bottom, or only 17 feet in all, though these beds contain a large supply of water.

In T. 24 S., R. 11 W., the next township west, the sands are thinner, a 105-foot well in the NW. ¼ sec. 21 having only 10 feet of sand in the bottom and a 300-foot hole in sec. 34 finding sand only at 78 to 80 feet, which yielded but little water.

Several wells recently sunk in the northwestern part of T. 24 S., R. 7 W., show an extension of a thick but variable succession of sands under that area. Detailed sections are given on another page, but a few general features will be mentioned here. A 140-foot well in the NW. ¼ sec. 1 has 70 feet of sand, not all water-bearing. A 130-foot well in the NE. ¼ sec. 11 has 35 feet, and one of about the same depth in the NW. ¼ sec. 11 has 56 feet of sands. In secs. 12 and 13 there are from 30 to 48 feet of sand in wells 122 to 128 feet deep. In a well in sec. 26 there are six sand deposits in 144 feet, aggregating about 46 feet.

Wells in T. 25 S., R. 9 W., show the wide extension of several thick beds of sand containing much water. The 550-foot boring in the SW. ¼ sec. 6 had sands at 50–90, 110–143, and 183–210 feet, or 160 feet in all, but a 150-foot well a mile to the southwest apparently found the principal water-bearing sand at 62–78 feet. A 150-foot well in the SW. ¼ sec. 10 had sands at 50–75, 102–112, and 135–145 feet, or 45 feet in all. A 148-foot well in the NE. ¼ sec. 148 had the first water sand at 52–69 feet and sand at intervals from 103 to 142 feet, probably about 35 feet of sand in all. A 110-foot well 2 miles farther east, in the NE. ¼ sec. 22, found 29 feet of sand but did not reach the fourth stratum. A 152-foot well in the NE. ¼ sec. 29 had sands at 55–73, 97–112, and 135–152 feet, or 50 feet in all. A well in the NW. ¼ sec. 35 reported only two sands, at 45–55 and 75–82 feet, or 17 feet in all, but possibly the supply is derived from another sand at the bottom. A well only 85 feet deep in the NW. ¼ sec. 18 of the next township east had 23 feet of sand, a 21-foot bed in the bottom containing much water. It is reported that 100 feet of sand was found in the bottom of a 275-foot well in the SW. ¼ sec. 18, T. 25 S., R. 10 W. A 191-foot well in the SW. ¼ sec. 18, T. 25 S., R. 11 W., found sand only at 60–65 and 182–191 feet, or only 14 feet in all.

In most parts of T. 26 S., R. 9 W., the water-bearing sands are thick and contain a large volume of water. An 80-foot well in the NW. ¼ sec. 3 has 40 feet of sand, but two wells 116 and 150 feet deep

in the southern part of this section have only 15 and 18 feet of sand, respectively. In the NW. ¼ sec. 18 sands were penetrated at 45–75, 110–120, and 145–155 feet, or 50 feet in all, and an 80-foot well in the southeastern part of the township showed five beds of sand at intervals from 30 to 80 feet, aggregating 25 feet.

In the Waterloo region and the vicinity of Palomas Arroyo, in T. 27 S., Rs. 9 and 10 W., the main water-bearing sand is near the surface and most of the wells penetrate it only from 20 to 30 feet to obtain all the water desired. A test hole in the SW. ¼ sec. 1, T. 27 S., R. 9 W., found sand and gravel at 27–46 feet, with clay below to the bottom of the hole at a depth of 105 feet.

In the Columbus region the sand deposits are varied in thickness and position, and in some districts the material is quicksand, which does not yield a satisfactory supply. In the SW. ¼ sec. 24, T. 28 S., R. 8 W., a 200-foot well penetrated 41 feet of sand, but it was mostly quicksand. Several wells about Columbus and farther south penetrated thick bodies of sand containing a large volume of water, but these deposits are irregular in size and of slight extent. In a 221-foot well in the northwest corner of sec. 11, 2 miles south of Columbus, gravel extends from 110 to 130 feet and sand from 165 to 221 feet, 76 feet in all, and this body of coarse material appears to extend southeastward to the international boundary.

VOLUME OF UNDERGROUND WATER.

It has been shown in preceding statements that the water-bearing deposits vary greatly in thickness, texture, and continuity from place to place, and that it is therefore difficult to determine accurately the amount of water stored in these deposits, and also that only an approximate figure can be offered as to the annual increment. It would appear that in most parts of the Deming region and the country to the south 40 feet is near the average for the aggregate thickness of the water-bearing beds in the first 150 or 200 feet below the surface. On the assumption that this 40 feet of sand contains 20 per cent of its volume in water, which is a fair average, the amount of water in a given area would be near 8 cubic feet to the square foot, equivalent to 60 gallons, or approximately 2,608,000 gallons to the acre, or 8 acre-feet. This is much more than the amount obtainable, because it is impossible to pump out all the water, the proportion available depending on the texture of the sand and some other minor factors.

The area under which there are 40 feet of water-bearing beds containing a fair volume of water is about 500 square miles, and with this volume at 8 cubic feet to the square foot, or 8 acre-feet for every acre, the underground water supply is 2,560,000 acre-feet. There is,

besides this area of 500 square miles, a region of large extent containing a smaller volume of water, some of which can be utilized for irrigation.

It is impossible to make an accurate estimate of the time required for the accumulation of this amount of water or for the replenishment of the supply if it were pumped out. Probably the few inches of increment from rainfall and the Mimbres underflow of 12,000 acre-feet, as above estimated, passing into the 14 townships which are in the line of its travel southward, would amount to an annual increment of less than half an inch for that area. At this rate many years would be required to fill the voids in the 40 feet of water-bearing beds.

GRADIENT AND RATE OF UNDERFLOW.

Gradient.—The word underflow implies a movement of the water down a grade of greater or less amount. The gradient and the porosity of the materials through which the water flows are the principal factors bearing on the rate of flow. The gradient in Luna County is represented on Plate VIII (p. 114), based on numerous accurate determinations of elevations of the water surface and many approximate data. In order to determine the altitudes south of Deming a special level line was run over the old grade road to the international boundary.

At Spalding the underground water is 30 feet below the surface, or 4,698 feet above sea level. At Deming it is 50 feet below the surface, or 4,290 feet above the sea, and at Columbus it is 30 feet below the surface, or about 4,033 feet above the sea. As the distance from Spalding to Deming is 17 miles, the down grade between the two places is therefore about 24½ feet to the mile. As the distance from Deming to Columbus is 31½ miles, the slope in that distance is 8.3 feet to the mile. At Iola the water surface is 46 feet below the surface, or 4,154 feet above sea level, a grade of slightly more than 7½ feet to the mile from Deming. At Gage the water level is 26 feet lower than at Deming, probably because the upper beds are too fine to admit any notable volume of water. This causes the long loop in the 4,300-foot line of grade shown in Plate VIII. There are some other deflections of the lines, due to special local causes, notably in the area of increased depth just south of Iola and in the area east of Columbus, where the lines apparently have a close relation to the topography. The strong deflection of the 4,100-foot line up the main Mimbres Valley east of the Florida Mountains defines the water plane in that bolson, where the water lies somewhat lower than on the west side. However, as the sediments on the east side are too fine to hold a large volume of water, the position of the

water plane is of little economic importance. There is a general rise of the water plane toward the high ridges, especially the Florida Mountains, where the alluvial fan holds a small underflow that moves down the slope.

Movement.—The rate of movement of the underground water in this region has not been tested at any point and can only be inferred in a general way from measurements in other regions. It diminishes somewhat with increase in depth, for in a region of low gradient increase in depth is accompanied by a proportionate decrease in grade. To judge from the water-bearing materials excavated at a number of wells, it is evident that the degree of porosity varies greatly. The rate of movement has been found to be as much as 100 feet a day in coarse materials, with the volume of water as high as 35 per cent, but in the average sand the rate is much less. Slichter and Wolff[1] found that the underflow of Platte River at Ogalalla, Nebr., had an average rate of 6.4 feet in 24 hours, or a mile in 825 days. At a depth of 16 to 22 feet the velocity averaged 12.8 feet a day, and at 55 and 85 feet it was 2.55 feet. The slope of the valley is about 8.3 feet to the mile. Slichter found that the underflow of Arkansas River at Garden City, Kans., averaged 8 feet a day, or a mile in 660 days, with a grade of 7½ feet to the mile. Much of the water of this underflow is derived from the side slopes, part of which are made up of loose sand, that imbibes 60 per cent of the rainfall.

In the Mesilla Valley, N. Mex., the underflow of the Rio Grande, having a grade of 4.6 feet to the mile, was found to have very slow movement,[1] and at the canyon of the Rio Grande, just above El Paso, Tex., the movement of the underflow, 10 to 20 feet below the bed of the river, was less than 3 feet a day.[2]

DEPLETION OF WATER SUPPLY.

Nearly 200 pumping outfits are installed or under erection in the Deming-Columbus region, and the average output will be near 700 gallons a minute for about 400 hours a year. If the number of pumps were placed at 500, which, however, is probably far in excess of the financial means of settlers now on the ground, the total yearly pumping of water for irrigation would be 8,400,000,000 gallons, or nearly 26,000 acre-feet. This would be equal to water 2 feet deep on 20 square miles, and with the duty of water at 2 acre-feet a season, 20 square miles to 500 ranches is equivalent to an average of only 25.6

[1] Slichter, C. S., and Wolff, H. C., The underflow of the South Platte Valley: U. S. Geol. Survey Water-Supply Paper 184, pp. 9–10, 1906.

[2] Slichter, C. S., Observations on the ground waters of Rio Grande valley: U. S. Geol. Survey Water-Supply Paper 141, pp. 9–13, 1905.

acres under ditch to each ranch. As 500 quarter-section homesteads occupy 125 square miles, the 26,000 acre-feet would be drawn from that area, where it would represent about one-third acre-foot of water, or less than 4 per cent of the 8 acre-feet available as estimated on page 120.

The estimated annual increment of 3 inches by rainfall and underflow would be sufficient to provide for the irrigation of only about one-eighth of the area in which the underground storage conditions are favorable, on the basis of the duty of water as 2 acre-feet an acre (2 feet deep over the area irrigated each season).

Of course 20 square miles under cultivation, as above estimated, is a very small proportion of the 125 square miles, or area of 500 homesteads, under consideration, nearly all of which could be irrigated by plants with an average of 700 gallons a minute. Eventually, no doubt, the proportion of land utilized in each homestead will increase, as it must for profitable operation, and then the draft on the underground supply will increase proportionately. If half of the area of the 500 homesteads were irrigated, the draft on the underground supply would be about 12 per cent instead of 4 per cent, and this would cause a serious diminution in the total amount available in some areas.

An important condition affecting the amount of the water that can be pumped from a particular area is the rate of lateral flow of the underground water. The movement is started when the pump begins to lower the water in the well, and the local depletion is more or less completely replaced by influx from a constantly widening area. In places where several heavy pumping plants are in close proximity, all drawing water at the same time, there will be a limit to the amount of water immediately available, and doubtless a scarcity of water would result at most localities. At many places the principal supply comes from a deeply buried stratum that is not very thick, and vigorous pumping drains out much of the water near the pump. A most important factor in underground flow is the relatively slow adjustment of water level compared with that of surface water, for the rate of movement in fairly coarse sand averages about 1 mile a year, or less than 15 feet in 24 hours. If, for example, there are four pumps of 1,000 gallons' output in the centers of four adjacent quarter sections, draining from a 5-foot bed of sand capable of yielding 20 per cent of its volume in water, or 1 foot deep for the total area, at the end of 20 hours' pumping the amount taken out by each pump would be 3.68 acre-feet—that is, all the water under 3.68 acres, or within a radius of about 200 feet. This is one-thirteenth of the distance to the next pump, and ordinarily water would require several days to flow this distance, the time depending on the head of the water and the porosity of the sand.

QUALITY OF THE WATER.

In general, the water from the wells of Luna County is moderate in mineral content and suitable for most uses. At a few localities the water, especially that near the surface, contains too much alkali, but this condition is unusual. Water from wells that are properly sunk and protected at the surface is free from contamination. The water pumped for irrigation in the broad area about Deming and to the south is nearly all low in mineral content and far above the average of waters of the West. However, all well and surface waters contain some mineral matter in solution; and if large volumes of these waters are allowed to evaporate on the land, this matter will gradually accumulate as "alkali" in or on the soil and poison it for plant growth.

Nine analyses of ground waters in this region are given in the accompanying table (p. 125). Most of them have been obtained through the courtesy of the chief engineer of the Southern Pacific Co. and Mr. H. J. Simmons, general manager of the El Paso & Southwestern System. They have been computed at the United States Geological Survey from conventional combinations in grains per gallon into ionic form in parts per million.

The water from the 85-foot well of the Southern Pacific Co. at Deming (analysis No. 1) is entirely acceptable for domestic use and for irrigation and is fair for boilers, being noncorrosive, low in foaming constituents, and capable of causing the formation of only a moderate amount of scale.

The water from the well at Gage (analysis No. 2) is acceptable for irrigation or for domestic use. As it is noncorrosive and low in foaming constituents and scale-forming ingredients, it may be considered fair for boiler use.

The water from the well at Cambray (analysis No. 3), though acceptable for domestic use, is rather poor for boiler use, because its high content of alkalies makes it likely to foam. It could be used for irrigation if care were taken to prevent accumulation of alkali.

The first stratum of the well at the Birchfield home ranch, in the Mimbres Valley east of the Florida Mountains (analysis No. 4), yields a sodium sulphate water of very high mineral content. A considerably less saline water was recently obtained at somewhat greater depth, but no analysis of it is available. The other two Birchfield wells yield waters considerably lower in mineral content (analyses Nos. 5 and 6).

Though the water from the railroad well at Columbus (analysis No. 7) is regarded as suitable for locomotives, the analysis indicates that it would be poor for that purpose because of its high con-

tent of foaming constituents. It would probably be acceptable for domestic use, but its high content of alkali renders it poor for irrigation.

The water from Carrizalillo Spring (analysis No. 8) is conveyed by pipe to Hermanas and is used by the El Paso & Southwestern System at that place. The analysis indicates that the water is acceptable for irrigation and domestic use. It is low in foaming ingredients and noncorrosive, and as it would probably form only a moderate amount of scale in boilers it may be classed as fair for boiler use.

The 503-foot boring at Arena (analysis No. 9) yields water too heavily charged with saline ingredients to be usable. It is unfit for boiler use because of its high content of foaming ingredients and it is too strong in alkali to be acceptable in irrigation. The same condition renders it unsuitable for domestic supply, though possibly it is drinkable.

Analyses of underground waters in Luna County, N. Mex.

[Parts per million.]

	1	2	3	4	5	6	7	8	9
Silica (SiO_2)	26	30	76	84	....	....	42	58	45
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	1.0	2.0	2.0	8.0	....	....	4.8	2.6	9.9
Calcium (Ca)	38	48	29	....	....	....	8.8	36	28
Magnesium (Mg)	8.2	7.5	11	30	....	....	3.1	17	14
Sodium (Na) } Potassium (K)	27	21	127				232	37	757
Sodium (Na)				858	360	300			
Potassium (K)				Trace.	32	26			
Carbonate radicle (CO_3)[a]	91	83	114	275	160	252	184	112	194
Sulphate radicle (SO_4)	21	27	102	1,176	150	144	155	24	903
Nitrate radicle (NO_3)	....	....	....	74	....	....	....	....	....
Chlorine (Cl)	13	22	67	445	284	53	52	20	435
Organic and volatile matter	....	....	....	61	....	....	....	....	178
Suspended matter	....	....	....	34	....	....	....	....	....
Total solids	224	240	527	3,011	1,090	840	682	308	2,564
Total solids in grains per United States gallon	13.1	14.0	30.8	175.9	59.0	4.9	39.9	18.0	150

[a] Carbonate and bicarbonate radicles not differentiated.

1. 85-foot well of the Southern Pacific Co., Deming. Sample collected Apr. 4, 1897, and analyzed by the company.
2. 340-foot well of the Southern Pacific Co., Gage. Sample collected Mar. 5, 1897, and analyzed by the company.
3. 269-foot well of the Southern Pacific Co., Cambray. Sample collected Feb. 23, 1897, and analyzed by the company.
4. First stratum in well of W. P. Birchfield, sec. 2, T. 25 S., R. 7 W. In Mimbres Valley east of the Florida Mountains. Analysis by Dearborn Chemical Co.
5. Well of W. P. Birchfield, 4 miles south of the home ranch in the bolson east of the Florida Mountains. Analysis by W. B. Hicks, U. S. Geological Survey.
6. Well of W. P. Birchfield, 10 miles southeast of the home ranch in the bolson east of the Florida Mountains. Analysis by W. B. Hicks, U. S. Geological Survey.
7. Well of the El Paso & Southwestern System, Columbus. Analyzed by the company.
8. Carrizalillo Spring. Analyzed by El Paso & Southwestern System.
9. Boring 503 feet deep at Arena. Analysis by El Paso & Southwestern System.

WELLS.

There are about 280 wells of various kinds in Luna County, most of them sunk within the last six years, and considerable well drilling is still in progress. Most of the wells are south and east of Deming,

the largest number of them being in Tps. 24 and 25 S., R. 9 W., T. 24 S., R. 8 W., and the southern part of T. 23 S., Rs. 8 and 9 W. There are also groups of them near Hondale, Iola, Waterloo, and Columbus. The distribution, depth, and depth to the water surface in wells are shown on the map (Pl. I, in pocket) and in the tables on the following pages. It has been found somewhat difficult to obtain complete data for all the wells, and for several of them the figures given by the driller and the well owner are not the same. The yields of the wells as given in the tables are the owners' or drillers' estimates and were not verified. The depth to the water surface was measured in some wells, but as a rule the figures were supplied by the owner or driller. Many important facts as to depth, water level, yield, and sections of material penetrated were supplied by Mr. R. H. Case, of Deming. In presenting the data for wells those in the vicinity of Deming will be given first.

T. 23 S., R. 8 W.

T. 23 S., R. 8 W., is next east of the township in which Deming is situated, its western margin lying 2 miles east of that city. Luxor, a siding on the Southern Pacific Railroad, is near the center of the township. Twenty wells have been reported in this area, mostly in the southern half. The principal facts regarding them are given in the following table:

Wells in T. 23 S., R. 8 W.

Location.	Depth.	Depth of water below surface.	Reported yield.[a]	Depth of water-bearing sands.
	Feet.	*Feet.*	*Gallons.*	*Feet.*
Sec. 3, NW. ¼ SW. ¼	....	....	Few.	
Sec. 3, SE. ¼ SW. ¼	....	80	Not tested.	
Sec. 12, NW. ¼ SW. ¼	105	65	480	65–72, 80–85, 88–92, 98–105.
Sec. 18, SW. ¼ SW. ¼	200	[b] 46	....	51–59, 110–141, 197–200.
Sec. 19, SE. ¼ SE. ¼	72	29	250	30–44, 53–70.
Sec. 20, NE. ¼ NW. ¼	200	54	50	
Sec. 21, NE. ¼ NE. ¼	87	28	200	Second stratum.
Sec. 23, SW. ¼ NW. ¼	115	30	400	45–50, 56–60, 66–80, 88–92.
Sec. 25, SW. ¼ NW. ¼	95	18	600	25–38, 50–60, 73–90.
Sec. 25, SW. ¼ SW. ¼	....	....	....	
Sec. 25, NW. ¼ SW. ¼	90	18	600	18–21, 69–71, 80–83.
Sec. 26, SW. ¼ NE. ¼	92	20	450	25–40, 52–62, 74–92.
Sec. 26, center of NW. ¼	180	28	500	
Sec. 27, NE. ¼ SE. ¼	103	20	800	20–23, 43–65, 72–75, 87–96.
Sec. 28, SE. ¼ NE. ¼	143	29	1,000	34–60, 65–83, 112–118, 136–143.
Sec. 29, SW. ¼ SE. ¼	710	24	800	Flowed originally. Water from 95 feet.
Sec. 30, SW. ¼ NE. ¼	....	34	300	
Sec. 31, NW. ¼ SW. ¼	140	30	1,000	
Sec. 32, center of SW. ¼ [c]	156	24	1,250	29–45, 80–103, 140–156.
Sec. 32, NE. ¼ NW. ¼	120	30	Many.	73–84, 116–120.
Sec. 35, SW. ¼ NE. ¼	78	15	Many.	15–23, 63–78.

[a] All yields in this report are in gallons a minute.
[b] Another report gives the depth of the water as 43 feet below the surface.
[c] Another report gives the depth as 145 feet and depth of the water as 29 feet below the surface.

The wide arroyo of the Mimbres extends across the southern part of the township and in its vicinity the water rises within 13 to 28 feet of the surface. The wells about Luxor find water at three principal horizons. In the 143-foot well on the Case ranch, in the east-central part of sec. 28, southeast of Luxor, the bore is 26 inches to 86 feet and 16 inches to the bottom. The casing is fitted with a strainer with 40 per cent perforations to take water from the 47 feet of sands which extend at intervals from a depth of 34 feet to the bottom of the well. The first water, at 30 feet, is shut out. The Paxton well, in the east-central part of sec. 27, a mile farther southeast and within half a mile of the river bank, penetrated 37 feet of water-bearing beds and obtained a large volume of water at 87 to 96 feet. Clay extends from 96 to 103 feet. The well is a 24-inch pit 40 feet deep, with a bore hole in the bottom 18 inches in diameter for 25 feet and 12 inches for the remainder. In the group of wells in the southeast corner of the township there are several wells 78 to 95 feet deep in which water rises within 15 to 20 feet of the surface and which have reported yields of 400 to 800 gallons a minute. In the Russell well, in sec. 25, 40 feet of water-bearing sands were penetrated. It is stated that in this well the water level sinks to 47 feet when the well is yielding 700 gallons a minute.

The Burdick well, in the southwestern part of sec. 29, 3½ miles east of Deming, was sunk to a depth of 710 feet in the hope of obtaining an artesian flow. The water now stands about 24 feet below the surface.

In the 156-foot well at the Shull ranch, in the SW. ¼ sec. 32, the first water at 29 feet does not rise, but the second water, at 80 to 103 feet, and the third or main water, in gravel and sand at 140 to 156 feet, rise within 24 feet of the surface. The well consists of a pit 2 feet in diameter and 50 feet deep, below which is a 9⅝-inch casing with screens at the second and third water beds. Heavy pumping for half an hour lowers the water to 45 feet below the surface, but it remains stationary at that level even for 12 hours with an output reported at 1,250 gallons a minute. In the NW. ¼ sec. 26 it was necessary to sink to a depth of 180 feet to obtain the volume required, but the water rises within 28 feet of the surface.

In the northern half of the township the water lies deeper and is of less volume than in the southern half. In the 200-foot well at the Hollis ranch, in the southwest corner of sec. 18, 42 feet of water-bearing sands in three beds were penetrated, but the volume of water is stated to be less than was expected. A 200-foot well in the NW. ¼ sec. 20 is closely similar to the Hollis well, with water 54 feet below the surface, but its pumping limit is stated to

be 50 gallons a minute. Both wells are in fine sand for the greater part of their depth.

Two trials for water have been made near Mirage siding, but only small yields were obtained, and in a new boring a few rods southeast of the siding the water is 80 feet below the surface. It is possible that the conditions will be found more favorable in the southwest corner of the township than they are to the southeast, but no wells have been sunk to test the water resources of that area.

T. 23 S., R. 9 W.

The city of Deming is situated in the south-central part of T. 23 S., R. 9 W., and the arroyo of Mimbres River crosses the township from west to east in secs. 19 to 23 and 25. In Deming there are many wells for domestic supply, mostly pumped by windmills, and also a city waterworks, which pumps from wells 139 feet deep. In the eastern part of the city the water surface is only about 45 feet deep, but the depth gradually increases to 58 feet in the western part of the city. In the trench cut by the river the depth to the water is 15 to 20 feet less.

The following is a list of the wells in this township, except most of the private wells in Deming:

Wells in T. 23 S., R. 9 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Depth of water-bearing sands.
	Feet.	*Feet.*	*Gallons.*	*Feet.*
Sec. 8, SE. ¼ NW. ¼		83		
Sec. 7, SE. ¼ NE. ¼	100	92		
Sec. 12, SE. ¼ SE. ¼	215	65		67-70, 85-86, 159-162, 185-191, 199-201, 210-212.
Sec. 17, NW. ¼	85	80	200	
Sec. 22, NE. ¼ NE. ¼		30		
Sec. 25, NW. ¼ SW. ¼	150	42	500	42-68, 88-98.
Sec. 25, SW. ¼ SW. ¼	143	44	1,150	44-62, 66-78, 85-100, 122-135.
Sec. 26, SW. ¼ NE. ¼ (Chinese Gardens).	160?	44?	400	
Sec. 26, NW. ¼ SE. ¼	164	40	600	40-58, 74-80, 86-90, 145-160.
Sec. 26, SW. ¼ SE. ¼	60	44	700	44-60.
Sec. 26, NE. ¼ SW. ¼	142	40		45-62, 104-120, 130-140.
Sec. 28, SE. ¼ SE. ¼ (city well, not in use).				
Sec. 29, NW. ¼ NE. ¼	154	51	1,000	61-68, 75-90, 102-108, 115-135, 148-154.
Sec. 29, NW. ¼ NW. ¼	70	62	(a)	62-68.
Sec. 30, NE. ¼ NW. ¼	203	63	Few.	65-83, 109-112, 190-200.
Sec. 31, SW. ¼ NW. ¼	120	64	1,000	65-96, 105-114.
Sec. 34, SE. ¼ NW. ¼ (in middle of town).				In middle of town.
Sec. 35, NW. ¼ NE. ¼	60	44		
Deming station (railroad well)	112	45	Many.	65-75, 90-95.
Deming waterworks, SW. ¼ sec. 27.	139	55	1,000	
Deming, new park at station	160	47	800	47-50, 84-105, 125-129, 140-145, 150-158.

a Windmill.

The wells in Deming obtain abundant supplies of remarkably pure water, mostly at 50 to 60 feet below the surface. The 139-foot well at the city waterworks, in the southwest corner of sec. 27, penetrated three water-bearing beds, but the main supply is obtained from sand at 90 to 105 feet, and when the pumps are raising 1,000 gallons a minute the water is lowered only a few feet. The water rises within 55 feet of the surface or to the top of the gravel containing the first water. The 112-foot well near the railroad station, a short distance east of the waterworks, furnishes the supply for the three railroads. The water surface in this well is 45 feet deep. In the new well at the city park in front of the Deming station, 160 feet deep, a deeper bed supplies the water.

The group of wells just east of Deming are mostly from 140 to 169 feet deep and each one yields from 400 to 1,000 gallons a minute. The water is used in greater part for irrigation of truck farms. The wells penetrate from 40 to 45 feet of water-bearing sands. Some wells west of Deming, in secs. 29 and 30, are 70 to 203 feet deep and most of them have developed large water supplies. One of these, in the northern part of sec. 29, is 154 feet deep and penetrated 43 feet of sands; another, 70 feet deep, had 6 feet of water and gravel; and a 203-foot well a mile to the west had 31 feet of water-bearing beds.

There are very few wells in the portion of this township lying north of Mimbres River, and some wells in that district have not yielded as large a supply as was expected. The depth to water increases toward the north, and probably it is 70 feet or more in the northeast corner of the township and near 100 feet in the southwest corner. This is indicated by the group of wells in secs. 7, 8, and 17, in which wells 85 to 100 feet deep have water at 80 to 92 feet below the surface.

The 215-foot well at the Brack ranch, in the southeast corner of sec. 12, throws much light on the underground conditions in the northeastern portion of the township. It penetrated seven thin sands at intervals from 67 to 212 feet, and finally obtained a fair supply of water rising within 65 feet of the surface. Clay extends from 212 to 515 feet.

T. 24 S., R. 8 W.

T. 24 S., R. 8 W., lies southeast of the township in which Deming is situated, and its northwest corner is 2 miles southeast of that city.

The underground waters have been reached by numerous wells, mainly in the northern, central, and western portions of the township. The following list includes all borings for which definite data could be obtained:

Wells in T. 24 S., R. 8 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Depth of water-bearing sands.
	Feet.	*Feet.*	*Gallons.*	*Feet.*
Sec. 1, SW. ¼ NE. ¼	....	16	Many.	
Sec. 2, SW. ¼ NW. ¼	96	17	400	17–31, 44–52, 88–96.
Sec. 2, SE. ¼ SE. ¼	60	a 4	....	
Sec. 3, SW. ¼ SE. ¼	....	18	750	
Sec. 5, NW. ¼ NW. ¼	114	30	700	54–65, 104–114.
Sec. 6, NW. ¼ NW. ¼	149½	32	1,200	50, 70, 85–110, 122–147.
Sec. 7, NW. ¼ NW. ¼	150	35	1,000	Mostly 46–100 feet.
Sec. 7, NW. ¼ SW. ¼	180	....	....	
Sec. 8, NE. ¼ NW. ¼	150	30	1,000	83–100.
Sec. 8, NW. ¼ SW. ¼	180	....	....	
Sec. 8, SE. ¼ SE. ¼	32	30	(b)	
Sec. 11, NW. ¼ NW. ¼	80	18	400	
Sec. 11, SW. ¼ SW. ¼	85	13	600	Third stratum.
Sec. 11, SE. ¼ SW. ¼	....	20	....	
Sec. 11, NE. ¼ NE. ¼	63	30	....	
Sec. 14, NW. ¼ SE. ¼	60	....	Many.	First bed.
Sec. 15, SE. ¼ NW. ¼	....	12	600	
Sec. 18, SW. ¼ NW. ¼	90	43	500	Do.
Sec. 18, SW. ¼ NW. ¼	110	44	700	87–96; clay below.
Sec. 18, SW. ¼ SW. ¼	150	48	700	
Sec. 19, SW. ¼ SE. ¼	70	43	....	
Sec. 20, SW. ¼ SE. ¼	1,665	17	800	50–62, 485–508.
Sec. 21, NW. ¼ NW. ¼	560	33	850	32–38, 60–65, 265–270, 319–325, 502–508.
Sec. 21, NW. ¼ NE. ¼	c 35	33	....	
Sec. 21, NE. ¼ NE. ¼	138	40	(b)	
Sec. 26, NE. ¼ NE. ¼	(d)	....	Not any.	
Sec. 27, NW. ¼ NE. ¼	d 80	....	(e)	
Sec. 28, NE. ¼ NW. ¼	40	....	(e)	
Sec. 30, NW. ¼	161	44	400	45–50, 67–96.
Sec. 33, NW. ¼ SW. ¼	....	....	Many.	

a Flows into long trench.
b Windmill.
c Another report gives the depth as 165 feet and the depth of water as about 35 feet.
d To rock.
e Quality unsatisfactory.

Several of the wells in the southern and western parts of this township are notable for the large volumes of water they yield, most of which is used for irrigation. One of the best known is the Hund well, in the northwest corner of sec. 6, which draws from the third bed at 149½ feet. A view of the outlet is shown in Plate X, *A*. It is pumped with a 35-horsepower engine and is reported to yield 1,200 gallons a minute, which draws down the water level to 49 feet below the surface.

The Hick well, in the northwest corner of sec. 7, draws its main supply from sand and gravel extending from 46 to 100 feet. A test hole at this place found nothing but clay from 150 to 170 feet. The water rises to the level of the first water at 35 feet, but it is stated that pumping at the rate of 1,000 gallons a minute lowers the water 15 feet.

In the E. ½ sec. 21 excellent water is obtained at a depth of 138 feet, apparently in large supply, but the water found at a depth of 40 feet was of bad quality. In the NE. ¼ NW. ¼ sec. 28 the water at 40 feet contains considerable mineral matter and can be used only for stock. A mile farther east, in sec. 27, an 80-foot well reached

A. DISCHARGE OF 1,200 GALLONS A MINUTE FROM A 150-FOOT WELL EAST OF DEMING, N. MEX.

Pumped by gasoline engine.

B. WELL ON YOUNG RANCH SOUTHWEST OF DEMING, N. MEX.

Pumped by electricity to yield 700 gallons a minute.

A. DITCH AT SOLIGNAC RANCH, 8 MILES EAST OF DEMING, N. MEX.

Dug to surface of underflow.

B. IRRIGATION DITCH 6 MILES SOUTH OF DEMING, N. MEX.

Flows 500 gallons a minute, pumped from well on bolson. View looking south. Florida Mountains in distance.

rock and found water in ample supply but too highly mineralized to use for irrigation. A well a mile still farther east, in sec. 26, reached rock and found no water.

At the Solignac ranch, which is in the Mimbres bottom lands, the underground water comes within 4 feet of the surface. It has been developed by a trench 40 feet long and about 10 feet deep, in the center of which a 9⅝-inch hole has been bored 60 feet to and into the second stratum. When water is pumped from the trench there is sufficient flow from the boring to yield a large amount of water for irrigation. Some features of this plant are shown in Plate XI, *A*.

At Berryman place, half a mile southeast of the Solignac ranch, the land is higher and the first water is 30 feet below the surface. The second stratum is at a depth of 54–63 feet and appears to contain a very large amount of water.

In the 96-foot well at Lesdo's ranch, a mile northwest of the Solignac ranch, the water rises to the top of the first stratum, or 17 feet below the surface. Three water-bearing sands were penetrated, containing 30 feet of sand in all, but the principal supply is from the second sand, at 44 to 52 feet.

On the McBride desert claim, in sec. 30, a 161-foot test well found the first water in coarse gravel at 45 to 50 feet. From 50 to 63 feet this well passed through compact clay, and from 67 to 96 feet alternations of clay, sand, and gravel containing considerable water, which rose within 44 feet of the surface and stood a pumping test stated to be at the rate of 400 gallons a minute. From 96 feet to the bottom there was clay with no water.

At the Stroup well, in sec. 19, a satisfactory water supply is obtained from an alternation of mud, gravel, and clay deposits beginning at 43 feet and extending to the bottom of the well at 70 feet.

The deep well in the south-central part of sec. 20 was sunk to a depth of 1,665 feet in the hope of obtaining an artesian flow. At 520 feet the water rose to 17 feet below the surface, or 23 feet higher than in shallow wells in the vicinity, and a supply of 800 gallons a minute was pumped in a test run with a 25-horsepower pump. Very little water was found below 520 feet, the depth from which the well is now pumped.

In a 560-foot boring in the northwest corner of sec. 21 only 28 feet of water-bearing sands were penetrated, with much fine compact material below 82 feet. The water rises within 33 feet of the surface, and it is reported that when the well is pumped at the rate of 800 to 1,000 gallons a minute the water is drawn down to a depth of 80 feet, where it remains while pumping continues.

T. 24 S., R. 9 W.

T. 24 S., R. 9 W., is next south to the township in which Deming is located and for 1 to 1½ miles its north line is the southern limit of that city. In this township there are many successful wells that afford a large amount of water, which is used mostly for irrigation. The following table gives the principal features of the wells so far as they could be obtained.

Wells in T. 24 S., R. 9 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Depth of water-bearing sands.
	Feet.	*Feet.*	*Gallons.*	*Feet.*
Sec. 2, NW. ¼ NW. ¼ (very old well).	....	....	....	
Sec. 4, SW. ¼ SE. ¼	90	52	400	52–80.
Sec. 4, NW. ¼ SE. ¼	80	52	400	
Sec. 4, SE. ¼ SE. ¼	50	47	200	
Sec. 5, NE. ¼ NE. ¼	55	52	....	
Sec. 5, NE. ¼ SE. ¼	55	50	....	
Sec. 7, NW. ¼ NW. ¼	150	60	600	
Sec. 7, NW. ¼ SW. ¼	200	61	450	No water below third stratum at 181 feet.
Sec. 8, center of SE. ¼	133	55	800 to 1,000	56–64, 68–74, 115–129.
Sec. 9, W. ½ SW. ¼	127	50	600	
Sec. 9, NE. ¼ SW. ¼	115	52	1,000	
Sec. 10, NW. ¼ NW. ¼	75	47	Many.	
Sec. 11, NE. ¼ SE. ¼	....	....	....	
Sec. 12, NW. ¼ NW. ¼	52	33	350	33–45.
Sec. 12, NW. ¼ SW. ¼	123	40	1,250	55–61, 66–78, 111–117.
Sec. 12, NW. ¼ NE. ¼	....	....	....	
Sec. 12, NW. ¼ SE. ¼	115	38	800	56–65, 78–86, 98–102, 108–113.
Sec. 12(?), SW. ¼ NE. ¼	128	42	....	58–68, 78–86, 105–114, 118–125.
Sec. 13, NW. ¼ NW. ¼	150	41	300	67–71, 80–85, 145–150.
Sec. 13, NW. ¼ NE. ¼	52	37	....	
Sec. 13, NW. ¼ SW. ¼	115	48	....	60–82, 103–115.
Sec. 13, SW. ¼ NE. ¼	128	42	875	58–68, 78–86, 105–114, 118–125.
Sec. 14, NW. ¼ NW. ¼	145	45	800	48–53, 65–72, 102–112, 125–129, 133–138.
Sec. 14, NW. ¼ SE. ¼	85	47	300	50–62, 78–85.
Sec. 14, SW. ¼ SW. ¼	....	57	....	
Sec. 15, NW. ¼ SW. ¼	100	50	....	59–62, 93–100.
Sec. 15, NW. ¼ SE. ¼	150	50	700	
Sec. 17, NW. ¼ NW. ¼	....	55	....	
Sec. 21, SW. ¼ NW. ¼	177	50	500	63–70, 83–88, 165–177.
Sec. 21, NW. ¼ SW. ¼	158	52	800	56–68, 124–134, 152–158.
Sec. 21, NW. ¼ SE. ¼	177	52	300	
Sec. 21, NW. ¼ NW. ¼	130	54	....	
Sec. 22, NE. ¼ NE. ¼	81	....	Many.	
Sec. 22, NE. ¼ NE. ¼	67	....	Few.	
Sec. 22, NW. ¼ SW. ¼	90	50	400	
Sec. 22, NE. ¼ SW. ¼	150	46	....	Third stratum 145 to 150 feet.
Sec. 22, SE. ¼ SE. ¼	61	51	25	
Sec. 23, NW. ¼ NE. ¼	79	52	....	52–79.
Sec. 23, NW. ¼ SE. ¼	89	45	1,200	45–74.
Sec. 24, NW. ¼ SW. ¼	....	....	....	In progress.
Sec. 24, NW. ¼ SE. ¼	110	43	600	46–51, 65–69, 85–89, 94–98, 103–108.
Sec. 24, NW. ¼ NE. ¼	....	46	....	
Sec. 25, NW. ¼ NE. ¼	145	42	600	50–60, 65–67, 71–74, 77–79, 103–108.
Sec. 26, NW. ¼ SW. ¼	[a] 158	52	350	
Sec. 27, NW. ¼ NE. ¼	150	50	700	
Sec. 27, NW. ¼ SW. ¼	149	52	100	
Sec. 28, NW. ¼ NW. ¼	203	53	700	53–75, 130–132, 158–162, 180–182.
Sec. 29, SW. ¼ SW. ¼	63	58	Many.	
Sec. 29, NW. ¼ NE. ¼	....	63	Many.	
Sec. 31, SW. ¼ NE. ¼	67	57	....	
Sec. 32, NE. ¼ NE. ¼	....	58	....	
Sec. 32, NW. ¼ SE. ¼	112	59	1,100	
Sec. 33, NE. ¼ SE. ¼	....	....	....	
Sec. 34, NW. ¼ SE. ¼	70	46	700	
Sec. 35, NW. ¼ SW. ¼	....	46	....	
Sec. 35, NW. ¼ SE. ¼	....	....	....	

[a] Another report gives 58 feet.

The volume of water appears to be large throughout the township, for large amounts are pumped for irrigation, and prolonged pumping reduces the water level only a few feet while the pumps are in operation.

The Young well (Pl. X, *B*, p. 130), in the northwest corner of sec. 28, is 203 feet deep and is the deepest one in the township. Although considerable water was found in the first stratum, at 53 to 75 feet, the main supply was reached in the second stratum, at 176 feet, and the amount increased somewhat as boring progressed. The water level is 53 feet below the surface and is lowered to 64 feet by 4 hours' pumping with a No. 5 pump having an 8½-inch discharge. The well is dug 55 feet with a diameter of 5¾ feet and bored 1 foot in diameter to the bottom.

The well at Sander's ranch, in the northwest corner of sec. 7, consists of a pit 12 feet in diameter and 84 feet deep, with two 6-inch holes in the bottom, one extending to 130 feet and the other to 150 feet below the surface. The water rises within 60 feet of the surface and is reported to yield 600 gallons a minute, with a temporary drop of only a few feet while the pump is in operation. On the next quarter section to the south is the Milliken well, 200 feet deep, which is reported to yield 450 gallons a minute, and a 10-hour run lowers the water surface only about 10 feet.

The well on the McBride ranch, near the center of sec. 12, consists of an 80-foot pit 2 feet in diameter with an 18-inch boring 40 feet deep in the bottom. Water was found at 40 feet, but the first notable supply is in gravel at 55 to 61 feet, and the main supply is derived from the third stratum at 111 to 117 feet. Between the second and third strata there are some additional thin water-bearing beds.

In the Bumpass well, in the center of the SE. ¼ sec. 8, water is obtained from the third stratum at a depth of 115 to 129 feet. Clay was penetrated at 64 to 68 feet and at 129 to 130 feet, and there are many alternations of clay and sand from 74 to 115 feet.

At the Bradshaw & McBride well, in the western part of sec. 12, the main supply is obtained from the second stratum, at 65 to 78 feet. It is reported that this well yields 1,250 gallons a minute and has been pumped steadily for three days and parts of the intervening nights without lowering the water level greatly, although pumping soon exhausts the water of the first stratum. Half a mile south of this well, in the northwest corner of sec. 13, is the Connaway well, which has given much less satisfactory results than neighboring wells to the north and west. The pump is set at a depth of 55 feet, and perforated screen extends from 60 to 150 feet, except in some caliche at 80 to 85 feet, where the screen is blank. A small amount of water occurs at 50 feet. It is reported that the well can be pumped

at a rate of 300 gallons a minute all day, but apparently this rate is the limit, for with greater production the water rapidly drops below the pump intake at 55 feet.

The Bowman well, in the northwest corner of sec. 12, indicates that the water conditions are more favorable to the north, for at a depth of only 52 feet it yields 350 gallons a minute for 18 hours a day pumping. A 6-horsepower engine is used. This well consists of a 6-foot pit 40 feet deep with a 10-inch boring in its bottom to the main water-bearing gravel at 52 feet.

T. 24 S., R. 10 W.

There are about 20 wells in T. 24 S., R. 10 W., most of them in its southeastern and central parts, with isolated wells in sec. 35 and southwest of Tunis. Red Mountain occupies an area of about 4 square miles in the central western part of the township, and the Snake Hills cut off the underground waters in secs. 32, 33, and 34. The following list presents all the data which could be obtained regarding wells in this township:

Wells in T. 24 S., R. 10 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Depth of water-bearing sands.
	Feet.	*Feet.*	*Gallons.*	*Feet.*
Sec. 1, SE. ¼ SW. ¼	67	60		
Sec. 12, NW. ¼ NW. ¼	69			
Sec. 12, NW. ¼ NE. ¼	135	64		64–90, 103–106, 115–118, 127–130.
Sec. 13, NW. ¼ SE. ¼	208	64		85–87, 113–118, 145–148, 196–203.
Sec. 14, NW. ¼ NW. ¼		58		
Sec. 15, NW. ¼ SE. ¼	160	65	500	
Sec. 15, NW. ¼ SW. ¼		65		
Sec. 28, N. ½	78	59	900	
Sec. 27, NW. ¼ NW. ¼	61	39		
Sec. 35, NW. ¼ SE. ¼	100	50	500	

So far as tested the waters in this township lie somewhat deeper than those in the adjoining township on the east and the water-bearing strata are less regular. In most of the wells the supply is satisfactory and fully as great as in the township east of this one. The first and second strata hold very small supplies, and in the center of secs. 15 and 13 it was necessary to go to the fourth bed, which in sec. 13 was found to lie at a depth of 196 to 203 feet. The water in it rises within 64 feet of the surface. At the Hughes well, in sec. 15, there was so little water in the upper beds that it was necessary to sink to a depth of 160 feet. The supply at that depth, however, was found to be so great that heavy pumping lowers the water surface only 5 feet, where it remains constant all day.

T. 24 S., R. 11 W.

T. 24 S., R. 11 W., lies west of Red Mountain, and the Southern Pacific Railroad crosses its northern portion. There are several wells in the northeastern sections which obtain satisfactory water supplies, but to the west and south the conditions appear to be less favorable. The following is a nearly complete list of the wells:

Wells in T. 24 S., R. 11 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Remarks.
	Feet.	*Feet.*	*Gallons.*	
Sec. 2, SE. ¼ SW. ¼	98	94	....	
Sec. 3, SE. ¼ SE. ¼	110	109	....	
Sec. 3, SE. ¼ NE. ¼	112	110	....	
Sec. 10, NE. ¼ SE. ¼	102	102	....	Windmill.
Sec. 11, NW. ¼ NE. ¼	185	94	100	Water at 94 feet.
Sec. 11, SE. ¼ NE. ¼	94	94	....	
Sec. 13, N. ½	160	90	....	Small pump.
Sec. 21, NW. ¼ NW. ¼	105	86½	Few.	Good supply in sand at 95 to 105 feet.
Sec. 34, W. ½	300	80	....	Water at 80 feet only.

Apparently the water supply is variable in amount, and the 300-foot boring in sec. 34 shows that in the southeastern corner of the township at least the volume is too small to be serviceable. The volume available in secs. 1, 2, 11, and 12 has not been fully determined, but the well in the NW. ¼ sec. 11, which is reported to yield 100 gallons a minute without materially lowering the water level, indicates a fairly large amount. In the low land in sec. 31 the water conditions may be favorable for a moderate supply, as indicated by the well a short distance to the south, in the next township.

T. 25 S., R. 8 W.

The northern half of the Florida Mountains lies in the eastern part of T. 25 S., R. 8 W., and the long western slope of the alluvial fans at the foot of the range extends to its western margin. The main underflow zone, however, underlies the western tier of sections and may extend some distance farther east, though there are no data to show its eastern limit. The McCann well, in the NW. ¼ sec. 18, is 85 feet deep, and the water in it rises within 38 feet of the surface. Some water-bearing beds were penetrated at 52 feet, and a thick body of sand extends from 62 feet to the bottom of the well. A pump run by a 35-horsepower engine is reported to raise 800 gallons a minute, and the water is used for irrigation. Another well 2 miles farther south is of less depth, and the water level is 37 feet below the surface.

No doubt other wells will be sunk on the slopes farther east in the township, and they will have a fair prospect of finding water in some of the coarser beds in the great alluvial fans of which this area is constituted.

T. 25 S., R. 9 W.

Underground waters are extensively utilized about Hondale and at various localities in nearly all parts of T. 25 S., R. 9 W. The following is a nearly complete list of the wells:

Wells in T. 25 S., R. 9 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Depth of water-bearing sands.
	Feet.	*Feet.*	*Gallons.*	*Feet.*
Sec. 1, NW. ¼ NW. ¼	92	45	250	Main supply, coarse gravel, 45–52½ feet.
Sec. 3, NE. ¼ NW. ¼	....	46	....	
Sec. 6, NW. ¼ SE. ¼	550 (214)	50	800+	50–90, 110–143, 183–210.
Sec. 7, NE. ¼ NW. ¼	....	....	100	
Sec. 7, NW. ¼ SW. ¼	150	60	800	62–78.
Sec. 10, NW. ¼ SW. ¼	150	50	....	50–75, 102–112, 135–145.
Sec. 14, SW. ¼ NW. ¼	52	48	....	
Sec. 15, NW. ¼ NW. ¼	150	50	(a)	
Sec. 17, NW. ¼ NW. ¼	....	57	75	
Sec. 17, NW. ¼ NE. ¼	75	53	70	
Sec. 17, NW. ¼ SE. ¼	....	51	....	
Sec. 18, NW. ¼ SE. ¼	....	55	....	
Sec. 19, NW. ¼ NW. ¼	....	55	....	
Sec. 19, NW. ¼ SW. ¼	....	48	....	
Sec. 20, SE. ¼ NE. ¼	148	52	....	52–69, at intervals, 108–142.
Sec. 21, NW. ¼ SW. ¼	95	49	650	
Sec. 22, NW. ¼ NE. ¼	110	45	1,200	45–54, 74–84, 100–110.
Sec. 24, NE. ¼ NE. ¼	165	35	1,000	
Sec. 24, NW. ¼ SW. ¼	98	38	450	66–76.
Sec. 24, SE. ¼ SE. ¼	51	37	....	Second stratum.
Sec. 25, NE. ¼ SE. ¼	....	31	....	
Sec. 26, SW. ¼ SW. ¼	158	32	310	
Sec. 27, NW. ¼ NW. ¼	147	50	(a)	
Sec. 29, center NE. ¼	152	50	(a)	55–73, 97–112, 152.
Sec. 30, NW. ¼ NW. ¼	150	50	(a)	
Sec. 33, NW. ¼ SW. ¼	152	55	600	
Sec. 34, NW. ¼ NW. ¼	....	49	....	
Sec. 35, NW. ¼ NW. ¼	140	42	1,000	45–55, 75–82.

[a] Installing; capacity not determined.

The deepest well in the township is in sec. 6, where a test boring reached a depth of 550 feet without finding any notable increase in volume of water below 210 feet. The supply is so great in sand extending from 183 to 214 feet that vigorous pumping lowers it only slightly while the pump is in operation. About Hondale the first water is at 54 to 57 feet below the surface, and this also is the level to which the water rises in the deeper wells.

In the northwest corner of sec. 35 the first water is in a bed of sand and gravel at 43 to 53 feet, and the main supply is obtained from a depth less than 100 feet.

In the north-central part of sec. 17, east of Hondale, a moderate supply of water is obtained from a 4-foot bed of sand and gravel which extends from 71 to 75 feet and is overlain by gravel and sand cemented by caliche.

T. 25 S., R. 10 W.

Several wells in the central and northwestern portions of T. 25 S., R. 10 W., and others in secs. 8, 17, and 18 have demonstrated the extension of the underground waters, and doubtless they will be

found to be available throughout the township. The following list presents the data obtained:

Wells in T. 25 S., R. 10 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Remarks.
	Feet.	*Feet.*	*Gallons.*	
Sec. 1, NW. ¼ SW. ¼	....	60	....	
Sec. 8, NW. ¼ SW. ¼	77	49	Many.	
Sec. 11, NW. ¼ NW. ¼	....	....	....	
Sec. 11, NE. ¼ NE. ¼	....	55	500	
Sec. 12, NW. ¼ SE. ¼	61	58	75	
Sec. 17, NW. ¼ NW. ¼	....	48½	Many.	
Sec. 18, NW. ¼ NW. ¼	126	60	500	
Sec. 18, NW. ¼ SW. ¼	275	55	300	Drawdown 10 feet; sand at 175-275 feet.
Sec. 22, NW. ¼ NW. ¼	....	52	....	
Sec. 24, NE. ¼ NW. ¼	100	49	400	
Sec. 15, center	160	65	500	

These wells show that the underground conditions are fairly uniform and that the water is in large volume. One well half a mile northwest of Hondale obtained an excellent supply from a depth of 61 feet, with the water level 58 feet below the surface. It has been tested only to 75 gallons a minute. In general the water lies deeper to the north and west, mainly because the land is slightly higher in that direction. Probably along the southern tier of sections the water will come within less than 50 feet of the surface.

At the Hughes well, in the center of sec. 15, the water is from the fourth stratum and the yield is reported to be 500 gallons a minute. The drawdown is only 5 feet in an all-day run.

T. 25 S., R. 11 W.

Two wells have been sunk at the Watkins ranches, in T. 25 S., R. 11 W. One recently completed at the 76 ranch is 130 feet deep and reaches the third stratum. The water rises within 32 feet of the surface and occurs in fair supply. When pumped at the rate of 1,000 to 1,200 gallons a minute the water sinks to 54 feet below the surface. A deeper boring is to be made to obtain water in still larger volume, in order to extend the irrigated area. The old wells at this ranch are 40 to 45 feet deep and are pumped by windmills to supply stock. A well sunk for Mr. Watkins in the northwest corner of the township is 150 feet deep to the second stratum, and the water rises within 110 feet of the surface. It also is pumped by a windmill.

At the Jordan ranch, in the SW. ¼ sec. 18, a well 191 feet deep has water within 38 feet of the surface and yields 400 gallons a minute. The first water was reached at 60 to 65 feet and the second at 182 to 191 feet. The well is in the arroyo.

The Darbyshire well, in the NW. ¼ NE. ¼ sec. 25, is 200 feet deep and obtains a good supply, which rises within 49 feet of the surface.

Probably the entire township is underlain by water-bearing beds at various depths, the depth increasing regularly with the rise of the land to the north and west. There may be masses of igneous or other rocks not far underground at some points, similar to the one which rises above the surface 2 miles east of the 76 ranch, and an occurrence of this kind would locally displace the water-bearing beds.

T. 26 S., R. 8 W.

There are several wells at ranches along or near the grade road in the southwestern portion of T. 26 S., R. 8 W. One in sec. 19 has the water level 40 feet below the surface. Another, in the NW. ¼ SE. ¼ sec. 30, is 36 feet deep and the water is 26 feet below the surface. In a third, in the northeast corner of sec. 31, the water is 21 feet below the surface. These wells obtain plenty of water for irrigation and domestic use and the one in sec. 30 is said to yield 500 gallons a minute. It found coarse sand at 26 to 36 feet. How far east toward the foot of the Florida Mountains the underground waters extend has not been fully determined, but a well recently sunk in the NE. ¼ SE. ¼ sec. 19 found water-bearing sand at 100 to 112 feet, from which water rises within 75 feet of the surface and appears to be in satisfactory volume. The results in this well indicate that more or less water-bearing material will be found nearly to the foot of the rocky slope.

T. 26 S., R. 9 W.

Wells in the central and northern portions of T. 26 S., R. 9 W., together with those in adjoining townships to the east and west, show a general extension of the underground waters in this district. The following is a nearly complete list of the wells in the township. Most of them supply water for irrigation.

Wells in T. 26 S., R. 9 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Depth of water-bearing sands.
	Feet.	*Feet.*	*Gallons.*	*Feet.*
Sec. 1, NW. ¼	....	38	....	
Sec. 2, center NW. ¼	....	....	....	
Sec. 3, NE. ¼ NW. ¼	80	40	700	40-80.
Sec. 3, SW. ¼ SE. ¼	116	40	....	34-35½, 52-80, 107-116
Sec. 3, NW. ¼ SW. ¼	150	40	....	73-80, 142-150.
Sec. 3, NW. ¼ NW. ¼	161	42	300	42-80.
Sec. 4, NW. ¼ NE. ¼	150	45	700	
Sec. 8, NW. ¼ NW. ¼	....	....	....	
Sec. 8, NE. ¼ SE. ¼	....	....	....	
Sec. 9, NE. ¼ NE. ¼	....	....	....	
Sec. 10, NW. ¼ NE. ¼	116	34	Many.	
Sec. 12, SW. ¼ NW. ¼	40	32	500	
Sec. 15, NW. ¼ SW. ¼	70	34	....	65-70.
Sec. 18, NE. ¼ NW. ¼	155	45	800	45-75, 110-120, 145-155.
Sec. 22, W. ½	....	40	....	
Sec. 24, NE. ¼ SW. ¼	55	27	800	Water in 20 feet of gravel.
Sec. 34, NW. ¼ NW. ¼	80	27	900	30-35, 40-48, 54-56, 60-65, 75-80.

The water is mostly 40 to 45 feet below the surface, except in the southeast corner of the township, where it probably stands at about 25 feet. In the western part of sec. 22 the water is 40 feet below the surface. The volume of water is great, for vigorous pumping lowers the water surface only a few feet in most of the wells and it rises again soon after the pump is stopped. A very satisfactory well in the northwest corner of sec. 3 is only 81 feet deep and found 38 feet of water-bearing sand. A well a mile farther southeast, in the southern part of sec. 3, obtains a large volume of water, mainly at the bottom of a 9-foot stratum of sand and gravel.

T. 26 S., R. 10 W.

Numerous wells about Iola and in the southeastern part of T. 26 S., R. 10 W., show that the underground waters are available under all of the area north of Palomas Arroyo, but the conditions are less favorable south of that valley. The wells so far reported are as follows:

Wells in T. 26 S., R. 10 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Remarks.
	Feet.	*Feet.*	*Gallons.*	
Sec. 1, NW. ¼ SW. ¼	110	49		
Sec. 2, SW. ¼ SE. ¼	74	50		
Sec. 3, SE. ¼ SE. ¼	51	49½		
Sec. 7, SW. ¼ SW. ¼	31	23		Windmill.
Sec. 9, NE. ¼ SE. ¼		50		
Sec. 10, NE. ¼ NE. ¼	160	49	300	
Sec. 10, NW. ¼ SE. ¼	156	50	325	
Sec. 10, NW. ¼ SW. ¼	100	53½	500	
Sec. 11, NW. ¼ NW. ¼		40		
Sec. 11, NW. ¼ SW. ¼	160	50		Do.
Sec. 11, NW. ¼ NE. ¼	50			
Sec. 14, NW. ¼ SW. ¼		40		
Sec. 14, NW. ¼ NW. ¼	49	46½		
Sec. 15, SW. ¼ SW. ¼	80	46		
Sec. 17, center of NW. ¼	90		40	
Sec. 17, SE. ¼ SW. ¼	42			Dug well; in rock below 79 feet.
Sec. 19, SW. ¼ NW. ¼	150		Few.	
Sec. 19, NW. ¼ SW. ¼	200		Few.	
Sec. 20, SW. ¼ NE. ¼	82	39		
Sec. 20, NE. ¼ SE. ¼	60			Rock at 57–60 feet.
Sec. 20, SW. ¼ SW. ¼	120	50	60	In rock.
Sec. 21, SW. ¼ NW. ¼	160	70	Few.	
Sec. 23, NW. ¼ SW. ¼		40		
Sec. 24, NW. ¼ NE. ¼	150	40	900	
Sec. 28, NW. ¼ NE. ¼	212	55		Pumps dry in a few minutes.
Sec. 28, NW. ¼ SW. ¼	98	60	Very few.	
Sec. 29, SE. ¼ NW. ¼	86			In rock; no water.
Sec. 29, NW. ¼ SW. ¼	200		Few.	
Sec. 33, NE. ¼ NE. ¼	112	110	Few.	
Sec. 33, center of SE. ¼	100	90	Few.	
Sec. 35, NW. ¼ NE. ¼		50		

The wells about Iola obtain large supplies of water at depths less than 100 feet, and the water rises within 40 to 50 feet of the surface. One well in sec. 10 is reported to pump 300 gallons a minute and another 600 gallons without reducing the water level greatly. A 150-foot well in the northern part of sec. 24 is reported to yield 900 gallons a minute, and continued pumping for irrigation lowers the water level only 11 feet.

The igneous masses in Midway Buttes cut off the water-bearing beds for some distance, but wells in the plain to the north and east obtain satisfactory supplies rising within 50 feet of the surface. The water conditions appear to be very irregular and mostly unsatisfactory in the southwestern quarter of the township. Some of the wells are in rock, which comes near to the surface and contains but little water, and some of that is of unsatisfactory quality. A deep boring in the NW. ¼ NE. ¼ sec. 28 found a small volume of water which rises within 55 feet of the surface but quickly pumps out. Possibly with greater depth a larger amount could be obtained in the wells that have been unsatisfactory. In the southwest corner of the township igneous rocks displace the water-bearing beds, and it is possible that the area in which this condition exists is of considerable extent.

T. 27 S., R. 8 W.

Underground waters have been developed by wells at short intervals in a zone extending along the slopes of Palomas Arroyo from northwest to southeast across T. 27 S., R. 8 W. These wells have shown that the water rises within less than 25 feet of the surface in part of the area and that there is a large volume of water available, at least near the arroyo.

The arroyo is more than half a mile wide where it crosses the line between the Florida and Tres Hermanas mountains. Undoubtedly it contains a large underflow moving slowly southeastward. Part of the water is from the upper course of the Palomas, but the larger volume comes from the wide bolson on the northwest, including the southern extension of part of the Mimbres Valley.

The following is a list of wells so far recorded in this township:

Wells in T. 27 S., R. 8 W.

Location.	Depth.	Depth of water below surface.	Reported yield.	Remarks.
	Feet.	*Feet.*	*Gallons.*	
Sec. 1, NE. ¼	250			No water.
Sec. 5, NW. ¼				Windmills (old wells).
Sec. 6, NE. ¼	39	22½	300	
Sec. 7, NE. ¼	34	23	950	
Sec. 7, NW. ¼ NW. ¼	40	24	1,000	
Sec. 8, SW. ¼ NW. ¼	37	21½	500	
Sec. 8, NW. ¼ NW. ¼	26	21	300	
Sec. 8, NW. ¼ NE. ¼	30	21		
Sec. 9, SE. ¼ NW. ¼	36	19	250	
Sec. 9, SW. ¼	39	25	300	
Sec. 11, NW. ¼	500	475		Salty water below 325 feet.
Sec. 12, NW. ¼	125			Small supply.
Sec. 15	23	18	50	
Sec. 17, N. ½ SE. ¼	20	17	Many.	
Sec. 23, NW. ¼ SW. ¼	192	21	700	
Sec. 25, SE. ¼ SW. ¼	85	30	150	
Sec. 25, NW. ¼		31		Two wells.
Sec. 27, NE. ¼ NE. ¼	37½	36½		Not tested.
Sec. 35, NE. ¼ NW. ¼	35	29½	750	

A. A WATERING PLACE IN THE DESERT.

Well with pump worked by burro supplies water for sheep. Typical view of bolson north of Tres Hermanas Mountains. Florida Mountains in distance.

B. DISCHARGE FROM WELL PUMPED BY GASOLINE ENGINE AT PIERCE RANCH NEAR COLUMBUS, N. MEX.

Shows the wide bolson of the Mimbres near the international boundary. View looking north.

The well shown in Plate XII, *A*, is in the N. ½ SE. ¼ sec. 17, in the bed of Palomas Arroyo. It is 20 feet deep, has a water level 17 feet below the surface, and furnishes a large supply of excellent water. A mile to the northeast is a well 39 feet deep, with the water level 25 feet below the surface, which is pumped for irrigation to the extent of 300 gallons a minute. There are two other similar wells 1½ miles farther north.

The Dixon well, in the northeastern part of sec. 6, penetrated 8 feet of compact loam, 27½ feet of loose sand, 1½ feet of clay, and 2 feet of quicksand in the bottom. In the western part of sec. 7 a large volume of water has been found rising within 23 to 24 feet of the surface. The test boring sunk at the Laffoon ranch, in the SW. ¼ sec. 23, to a depth of 192 feet with the expectation of finding water that would rise higher in the well obtained no large supply below the first stratum at 21 feet, which affords ample volume. Most of the material penetrated was "cement gravel" containing some water and including several thin water-bearing sands that gave no notable increase in volume or head.

In two wells in the NW. ¼ sec. 25 the water is within 31 feet of the surface, and although only a moderate volume is now being pumped it is said that much more could be obtained.

In the center of the township the underflow apparently does not extend far southwest of the Palomas Arroyo, for the rocks of the Tres Hermanas Mountains soon rise in that direction. Farther south the conditions have not been tested, and there may be a considerable area in which water may be available. A few wells in the northeastern portion of the township indicate rather unfavorable conditions. A 500-foot boring in the NW. ¼ sec. 11 obtained only salty water and no water above 325 feet, and two wells to the east and northeast had most unsatisfactory results.

T. 27 S., R. 9 W.

There is a group of successful wells about Waterloo on the northeastern corner of T. 27 S., R. 9 W., which furnish water for extensive irrigation. They are all near Palomas Arroyo, and in all except one the water rises within 23 feet of the surface. The wells are from 25 to 30 feet deep, with the exception of an old one at the 3 C ranch, which is 39 feet deep and contains only 4 feet of water, though this is enough to serve for ranch use. The Peters & White well, at Waterloo post office, is 30 feet deep and has 7 feet of water-bearing sand and gravel in its bottom. A test hole 16 feet deeper was entirely in gravel. The yield of this well is 600 gallons a minute, and two other wells in the group furnish similar amounts. A well in the northwest corner of sec. 1 is 30 feet deep, and the water rises

within 23 feet of the surface and furnishes about 600 gallons a minute. Coarse, loose water-bearing gravel was entered at 23 feet, and a test hole continued to a depth of 46 feet did not reach the bottom of that material.

The Manning well, in the SW. ¼ sec. 1, is 40 feet deep, and the water rises within 23 feet of the surface. It furnishes 1,000 gallons a minute for the irrigation of 30 acres. The Watkins well, in the NE. ¼ sec. 3, is 105 feet deep and has water within 27 feet of the surface. It found gravel extending from 27 to 46 feet, with plenty of water, but clay from 46 to 105 feet.

There are several wells along the Palomas Arroyo in secs. 4 to 6. One in the NE. ¼ sec. 4 is 50 feet deep, and the water rises within 33 feet of the surface and pumps 300 gallons a minute. It is in 12 feet of gravel. Half a mile farther west is a shallow well, with water 33 feet below the surface. In the SW. ¼ sec. 5, a 50-foot well has water 35 feet below the surface and is pumped by a windmill for stock. In the northeast corner of sec. 6 a 36-foot well, with 6 feet of water in it, pumps 20 gallons or more a minute, and a well in the NW. ¼ SE. ¼ of the same section is 40 feet deep and has 1 foot of water in it, apparently only in small volume.

T. 27 S., R. 10 W.

Underground waters have not been extensively developed in T. 27 S., R. 10 W., and the principal use for water has been for stock. There are several fairly satisfactory wells in the lowlands in the northeast corner of the township. One in the NE. ¼ sec. 1 is 50 feet deep, has water within 41 feet of the surface, and yields 32 gallons a minute. A 60-foot well in the northwest corner of sec. 12 contains 3 feet of water and yields a fair supply. A 72-foot dug well in the NE. ¼ NW. ¼ sec. 3 appears to be satisfactory. Wells at the old ranch 2 miles east of Tomerlin are 160 feet deep and obtain water at 100 feet, which rises within 90 feet of the surface, but the supply is small.

COLUMBUS REGION.

Underground water is extensively developed about Columbus in the wide bolson traversed by Palomas Arroyo. The wells range from 25 to 200 feet in depth and obtain water, which rises within 2 feet of the surface near the international boundary but only within 50 feet or more in the area farther north. The volume is large at most places, but several of the wells southeast of Columbus have not obtained a sufficient amount for irrigation. The following list gives the principal features of most of the wells:

Wells in the Columbus region.

Location.	Depth.	Depth of water below surface.	Reported yield.	Remarks.
T. 29 S., R. 8 W.	*Feet.*	*Feet.*	*Gallons.*	
Sec. 1, SW. ¼ SE. ¼	23	12		Windmill.
Sec. 3, NE. ¼ NE. ¼	200	46	500	
Sec. 11, NW. ¼ NW. ¼	221	12	1,200	Second water at 165–221 feet.
Sec. 12, center of SE. ¼	250	17	1,000	Third water at 224–250 feet; chief supply.
Sec. 12, SW. ¼	187	3½	Many.	
Sec. 13, NW. ¼ NW. ¼	185	2	2,000	Water at 126 feet; none below.
Sec. 13, NW. ¼ NW. ¼	165	2		Second water.
Sec. 14, west-central part	165	25		Water begins at 95 feet.
T. 28 S., R. 8 W.				
Sec. 1, NW. ¼	35	30	300	
Sec. 2, SE. ¼	77	57		Domestic supply.
Sec. 3, NW. ¼	146	78		First water at 90 feet, not much; second water at 132–146 feet.
Sec. 9, S. ½	258	200	25–40	
Sec. 10, NE. ¼	177		6	
Sec. 11, NE. ¼		60		Dug well, good supply.
Sec. 11, N. ½ SE. ¼		42 72		
Sec. 15, SW. ¼ NE. ¼	165	100		First water at 135 feet.
Sec. 17, SE. ¼	120		0	
Sec. 20, NE. ¼	253		0	
Sec. 21, NE. ¼		205		
Sec. 22, NE. ¼	209	120	60	First water at 140 feet; second water at 175 feet.
Columbus, railroad well	330	30		
Do	122	32		First water.
Do	70, 73	40		
Do	152	41		
2 miles north of Columbus	398½	70		Mainly at 160 feet.
Sec. 22, NW. ¼	300	138	80	Water at 205 feet.
Sec. 24, NW. ¼ SW. ¼	200	32½	10	
Sec. 26, NW. ¼ NW. ¼	217	29	150	Supply at 188–217 feet.
Sec. 35, NE. ¼ SW. ¼	151	40	Many.	
T. 29 S., R. 7 W. (UNSURVEYED).				
Sec. 6, NW. ¼	160		Few.	
Sec. 7, SW. ¼	246	4	2,000	
Sec. 8, SE. ¼	250	12		
Sec. 9	500	12	Few.	
T. 28 S., R. 7 W.				
Sec. 3, NE. ¼	120	90	Few.	Stock well.
Sec. 4, SW. ¼	50	40	10	
Sec. 4, W. ½	42	36	Few.	Fine sand.
Sec. 5	147	12	Few.	Shay ranch. Bored 1,000 (975) feet; water at intervals from 43 feet. Not tested.
Sec. 6, NW. ¼	45	38½	150	
Sec. 6, SE. ¼	45		Few.	
Sec. 7, SE. ¼	40		Few.	
Sec. 7, NW. ¼	45	40		Not tested.
Sec. 7, SW. ¼	78			
Sec. 8, NW. ¼	204		Few.	
Sec. 8, SE. ¼	44	42	1	
Sec. 8, SW. ¼	45	40	2	
Sec. 8, SW. ¼	46	43	12	
Sec. 9, SW. ¼	43	32	15	
Sec. 9, NW. ¼	40		Few.	
Sec. 9, SE. ¼	80		Few.	
Sec. 10, SW. ¼	90	90	Few.	
Sec. 14, SW. ¼	95	95	Few.	
Sec. 15, NW. ¼	90		Few.	In 10-inch sand bed.
Sec. 15, SW. ¼	85	77	Few.	
Sec. 17, NE. ¼	47	40	40	
Sec. 17, NW. ¼	45		Few.	
Sec. 17, SW. ¼	50		Few.	
Sec. 18, NW. ¼	83		Few.	
Sec. 18, NE. ¼	46		Few.	
Sec. 18, SE. ¼	46			Fair supply.
Sec. 19, SE. ¼	130			No water.
Sec. 20, NW. ¼	240		Few.	Do.
Sec. 20, SW. ¼	130			No supply.
Sec. 21, NW. ¼	130			Small supply.
Sec. 21, SE. ¼	107			Do.

Wells in the Columbus region—Continued.

Location.	Depth.	Depth of water below surface.	Reported yield.	Remarks.
T. 28 S., R. 7 W.—continued.				
Sec. 21, SW. ¼	226	....	Few.	Fine sand.
Sec. 22, SW. ¼	91	85	Several.	
Sec. 24, NW. ¼	109	....	Few.	
Sec. 25	100	....	....	Fair supply.
Sec. 26, SE. ¼	510	3	....	Flowed at first.
7½ miles east of Columbus	106	....	....	Very little water.
Sec. 27, SE. ¼	200	....	....	Very little.
Sec. 30, SW. ¼	355	....	....	Small supply.
Sec. 30, SE. ¼	200	....	....	Do.
Sec. 31, SW. ¼	200	....	....	Very little.
Sec. 33, SE. ¼	30	....	....	No water.
Sec. 35, NW. ¼	285	....	....	Do.
Sec. 35, north-central part	290	92	10	Quicksand with water at 128, 185, and 285 feet.
T. 27 S., R. 7 W.				
Sec. 26, SW. ¼	500	....	....	
Sec. 30	300	....	....	Small supply.
Sec. 31, SW. ¼	45	37	200	
Sec. 32	50	36	Many.	
Sec. 34, SW. ¼	130	110	Few.	Do.

All available information regarding most of these wells is given in the table. The Bailey well, in sec. 13, was the first to test the underground water conditions in the southern part of Luna County. It is only about 2 miles north of the large springs known as Ojo de las Adjuntas, in Mexico, where the underflow of Palomas Arroyo comes to the surface and accumulates in the Palomas Lakes. It developed a large volume of water at 126 feet, rising within 2 feet of the surface, but when the pump is producing 2,000 gallons a minute the water gradually drops to 7 feet below the surface, where it remains stationary. It is stated that the water level in a second well a few feet away is not noticeably affected by this draft on the underground supply. At this well the first water is in gravel and sand extending from 12 to 40 feet and it rises only to 12 feet below the surface. At the old Bailey ranch, in sec. 14, a few rods north of the international boundary, the main water supply is obtained from sandy beds, which occur at intervals from 95 to 165 feet, and the water rises within 25 feet of the surface.

In the Pierce well (Pl. XII, *B*, p. 140) in the center of the SE. ¼ sec. 12, half a mile northeast of the Bailey irrigation well, the water rises within 6 feet of the surface. Rock was reported in this well from 197 to 250 feet. Water was found at depths of 25, 65, 177, 194, and 225 feet, increasing in volume and head to 250 feet. The water at 194 feet came within 17 feet of the surface and that at 240 feet within 12 feet of the surface. When the well is pumped at the rate of 1,000 gallons a minute the water level is not greatly lowered, and the same thing is true of most of the wells at and south of Columbus.

In the well of Mrs. English, in the southwest corner of sec. 12, 3 miles southeast of Columbus, water from a depth of 187 feet rises within 3½ feet of the surface. In the Keenum well, in the northwest corner of sec. 11, 2 miles south of Columbus, water from a depth of 221 feet rises within 12 feet of the surface. The first water at the Keenum well is in gravel, extending from 110 to 130 feet. This stratum is underlain by 4 feet of "malpais" (basalt?), 31 feet of clay, and 56 feet of sand, extending from 165 to 221 feet. The well is cased with 8 and 6 inch pipe.

In the 246-foot well at the Hallock ranch, half a mile east of Pierce's, the water rises within 4 feet of the surface. The first flow was found in rock at a depth of 200 feet, and the second at 225 feet. The material above the rock is clay with thin deposits of sand containing water at 30 and 135 feet, but these waters did not rise. An 18-horsepower engine and a No. 7 pump with 10-inch discharge yields, it is said, 2,000 gallons a minute without greatly lowering the water. In the 250-foot well on the Poole ranch, half a mile farther east, the water comes within 12 feet of the surface. Hard rock, supposed to be "malpais," overlain by 5 feet of blue clay, was entered at 246 feet. At 165 feet and again at 200 feet there was sand which yielded some water that rose within 50 feet of the surface. "Alkali" water was found at 35 feet, and water of good quality, which rose within 53 feet of the surface, at 78 feet.

In the 500-foot boring in sec. 9 the water rises within 12 feet of the surface, but the supply is so slight that a small engine pumps it down to 170 feet in 20 minutes. Water-bearing sand was found at 210 feet. The materials to 308 feet were largely red clay. Blue clay extended from 308 to 320 feet, soft red rock which yielded a small amount of water from 320 to 340 feet, and a very hard black rock, regarded as "malpais," from 340 to 500 feet.

The wells near Columbus find somewhat variable water conditions, as they are some distance west of the main arroyo. The railroad well, 330 feet deep, with water at about 30 feet below the surface, obtains plenty of water for locomotive supply. (For analysis, see p. 125.) In another well near by the first water is obtained at 122 feet and rises within 32 feet of the surface. Two wells south of the railroad have water in moderate amount at 70 and 73 feet. In the 200-foot well on the Waterbury ranch, half a mile to the south, water is within 46 feet of the surface. In the 151-foot well at the De Rosear ranch, half a mile southeast of Columbus, water is within 40 feet of the surface, and a small amount of water that rose within 60 feet of the surface was found at 110 feet. Clay extended from 110 to 145 feet, where the water-bearing sandstone was entered.

A well 398½ feet deep 2 miles north of Columbus found the first main water-bearing bed at 160 feet, from which water rose within 80 feet of the surface, and with increase in depth the water finally rose within 70 feet of the surface. The 258-foot well at the Stearly ranch, in the SE. ¼ sec. 9, T. 28 S., R. 8 W., is somewhat similar, but the water is 200 feet below the surface. As the lift is great a 4-inch cylinder pump is used with a yield reported to be 25 to 40 gallons a minute, but it is said that with more power the yield might be greatly increased.

On the Thomas ranch in the NW. ¼ SW. ¼ sec. 24, T. 28 S., R. 8 W., it was necessary to sink 200 feet, but the water rises within 32½ feet of the surface and furnishes a satisfactory supply for ranch use. The first water was found at a depth of 94 feet. The beds penetrated were as follows:

Record of well in the NW. ¼ SW. ¼ sec. 24, T. 28 S., R. 8 W.

	Feet.
Loam, clay to sandy	0–20
Sand (clean)	20–29
Gravel	29–31
Clay and compact sand	31–94
Quicksand	94–98
Clay	98–118
Quicksand	118–143
Clay and quicksand alternating (2 to 3 feet)	143–197
"Hardpan"	197–199
Sand and gravel with water (thickness unknown)	199–200

The 217-foot well at the Peters & White ranch, in the northwest corner of sec. 25, 2 miles northeast of Columbus, reached water-bearing sands at 188 feet, in thin deposits between beds of red clay. The water came within 29 feet of the surface and was satisfactory in amount. In a well only 10 feet from this one the strata reported from 200 to 300 feet, were gravel with thin deposits of clay at intervals.

In a 65-foot dug well at the Hansen ranch, in the SE. ¼ sec. 2, T. 28 S., R. 8 W., the water rose 8 feet and was sufficient for ranch use, but the well was finally clogged up with quicksand. Another well 200 feet away found harder sand at 67 to 77 feet from which water rose 20 feet in the well. In two other wells in the N. ½ SE. ¼ sec. 11, in the same township, 60 rods apart, water was obtained at 42 feet in one and at 72 feet in the other.

In the 300-foot well at the Engendorf place, on the grade road 2½ miles northeast of Columbus, the main supply was found at 205 feet and rises within 138 feet of the surface.

Most of the wells near Palomas Arroyo, northeast of Columbus, are in the western half of T. 28 S., R. 7 W. They are mainly 35

or 40 feet deep and obtain only moderate supplies of water. In most of them the water-bearing bed is fine sand or quicksand. A 240-foot well in the NW. ¼ sec. 19 failed to procure a supply. It is reported that a 975 or 1,000 foot boring at the Shay ranch, in sec. 6 (or 7), T. 28 S., R. 7 W., found water at intervals from 43 feet down, but the supply was small. A well in sec. 32, T. 27 S., R. 7 W., obtains a supply of water at a depth of 36 feet, which is pumped for irrigation. Wells farther east in this township have obtained but little water. One 500-foot boring in the SW. ¼ sec. 26 found a very small supply, and a 300-foot boring in the SW. ¼ sec. 30 is reported unsatisfactory. Wells in secs. 35, 26, 27, 22, and 15, T. 27 S., R. 7 W., yield only small volumes of water.

The Kaltenmeyer well, 44 feet deep, in the SE. ¼ sec. 8, T. 28 S., R. 7 W., has a 12-foot tunnel, in the bottom of which water accumulates to the amount of about 5 barrels, and this is pumped out three times a day. Another well 500 feet to the west is slightly deeper and contains 5 feet of water which yields about 2 gallons a minute. Unfortunately the clay in suspension clogs the strainer and stops the flow when the pumping cylinder is sunk more than 3 inches into the water. Many wells from 40 to 204 feet deep in the northwestern and west-central part of this township (T. 28 S., R. 7 W.) have failed to obtain a satisfactory supply, except for moderate domestic use, and wells 200 to 355 feet deep in the southwestern and southern parts of the township have had similar results.

There are several wells in the southern and eastern parts of this township, but many of them contain a very scanty water supply and several borings failed to obtain sufficient water for domestic use. The sand is in thin deposits, and much of it is quicksand. A boring recently made in the NE. ¼ sec. 26, T. 28 S., R. 7 W., found but little water until it reached a depth of 510 feet, where a small flow was found. This flow continued for a time but finally ceased, and the water was 3 feet below the surface in the summer of 1913. It is said that the flow stopped because of clogging in the lower part of the casing.

Several deep wells have been sunk west of Columbus, and though some of them have obtained small supplies others have been dry holes. The Hoppe well, in the SW. ¼ sec. 4, T. 29 S., R. 9 W., 9 miles west of Columbus and 2 miles north of the international boundary, is 500 feet deep. The water rises within 380 feet of the surface and yields 6 gallons a minute to a 16-foot windmill. It is stated that the water is of excellent quality. Four miles to the southeast, on the Moaty ranch, is a 300-foot well with 100 feet of water, and 5 miles to the south, on the Lane ranch, a 250-foot well has 50 feet of water. Within 3 or 4 miles of the Hoppe ranch, however, there are four dry holes 300 to 400 feet deep.

CARNE REGION.

DEVELOPMENT OF UNDERGROUND WATER.

Underground waters have been extensively developed by wells about Carne and in the region extending southward down the Mimbres Valley. In part of the area the volume of water is large and it is being utilized for irrigation. The following list gives most of the facts obtained regarding the wells:

Wells in Carne region.

Location.	Depth.	Depth of water below surface.	Reported yield.	Depth of water-bearing sands, in feet, and remarks.
T. 23 S., R. 7 W.				
	Feet.	*Feet.*	*Gallons.*	
Sec. 10, SE. ¼ SE. ¼	103	100½	Domestic supply.	
Sec. 12, NW. ¼ NW. ¼	294	55½	...	Fifth stratum.
Sec. 19, NW. ¼	147	70	...	70–78, 102–108, 130–147.
Sec. 21, SW. ¼ SW. ¼	195	70	800	74–87, 89–117, 177–195.
Sec. 22, NW. ¼ NE. ¼	150	80	Few.	
Sec. 25, SW. ¼	90	78	...	18–21, 69–71, 80–83.
Sec. 26, NE. ¼	92	20	...	20–23, 43–47, 77–90.
Sec. 29, SW. ¼ SW. ¼	40	28	...	
Sec. 30, SW. ¼ SW. ¼	111	22	800	22–24, 29–35, 64–77, 77–101.
Sec. 30, NW. ¼	90	23	...	23–28, 32–38, 65–71, 75–77, 82–86.
Sec. 34, NE. ¼	98	51	1,000	51–53, 63–64, 78–81, 83–84.
T. 24 S., R. 7 W.				
Sec. 1, NW. ¼ NW. ¼	120	47½	...	
Sec. 1, NW. ¼	140	48	1,000	48–54, 66–70, 75–80, 82–140.
Sec. 2, E. ½ E. ½	139	45	1,500	88–128.
Sec. 3, NW. ¼ NW. ¼	76	44	Not tested.	
Sec. 4, SE. ¼	...	50	...	
Sec. 4, NE. ¼, NE. ¼	80	46	...	
Sec. 4, SW. ¼ SE. ¼	124	47	125	117–124 (first water at 72).
Sec. 6, NE. ¼ lot 2	50	33	...	Windmill.
Sec. 8, NW. ¼	...	47	...	
Sec. 9, NE. ¼ NW. ¼	85	43	1,000	
Sec. 9, NW. ¼	64	50	...	
Sec. 11, NE. ¼	130	49	1,500	49–64, 75–82, 93–99, 123–130.
Sec. 11, NW. ¼	156	46	1,800	46–73, 77–85, 87–93, 95–110, 113–123.
Sec. 11, NW. ¼ NW. ¼	125	46	Good supply.	
Sec. 13, NW. ¼	122	66	1,000	66–67, 71–81, 84–99, 103–122.
Sec. 12, NW. ¼ NW. ¼	106	48	1,000	48–57, 60–64, 74–79, 94–99.
Sec. 12, NE. ¼	128	49	1,000	49–58, 66–78, 90–91, 94–107, 121–128.
Sec. 12, SW. ¼	122	48	1,000	48–58, 68–73, 83–97, 102–122.
Sec. 15, NE. ¼ NE. ¼	...	50	...	
Sec. 26, N. ½ SW. ¼	160	76	1,000	76–78, 86–99, 110–119, 121–144.
Sec. 27, N. ½	64	62	Not tested.	
Sec. 36, NW. ¼ NW. ¼	75	71	...	
T. 24 S., R. 6 W.				
Sec. 6, NW. ¼ NW. ¼	135	80	...	Good quality.
Sec. 7, southeast corner	200	...	No water.	In progress.
T. 25 S., R. 7 W.				
Sec. 2, SE. ¼ SE. ¼	94	82	Good volume.	Quality bad.
T. 23 S., R. 6 W.				
Sec. 22, SE. ¼ SE. ¼	80	75	Not tested.	
Sec. 27, NW. ¼ SW. ¼	275	80	250	
Sec. 30	92	90	3	

WELLS.

T. 23 S., R. 7 W.—There are several wells about Carne which obtain excellent supplies of water for domestic use or irrigation. On the Glasser ranch, in the SW. ¼ sec. 30, there are two wells yielding a large amount of water for irrigation. One is 111 feet deep and the other 40 feet deep, with water 22 feet below the surface. The deeper of these wells penetrated the following materials:

Record of well in the SW. ¼ sec. 30, T. 23 S., R. 7 W.

	Feet.
Clay, etc	0–22
Gravel	22–24½
Clay	24½–29
Gravel	29–34½
Sand (packed)	34½–40
Clay	40–50
Sand	50–55
Clay	55–63
Sandrock	63–65
Quicksand	65–66
Gravel and sand, water	66–72
Clay	72–75
Very coarse gravel	75–76
Gravel, water	76–79
Soft sandrock	79–111

A 147-foot well in the NW. ¼ sec. 19 found the water 70 feet below the surface. This well penetrated 29 feet of water-bearing sands, but the third stratum, from 130 to 147 feet, contained the main water supply.

At the Connor well, in the SW. ¼ sec. 21, 1½ miles northwest of Carne, the main water supply is in 18 feet of sand and gravel at 177 to 195 feet, and it rises within about 70 feet of the surface. The well consists of a pit 5 feet in diameter and 74 feet deep, a 30-inch hole 13 feet deep, with screen casing, and 18 and 12 inch casing with screens to the bottom. Sand and gravel were the principal materials penetrated. At a depth of 87 feet there was a 2-foot layer of rock, and at 117 feet a 1½-foot layer. Below the lower layer was 60 feet of tightly packed sand and clay. The first water was found at 74 feet, the second water appeared at 90 feet and rose 2 feet higher than the first, and there was a rise of an additional 18 inches in the third water, at 119 feet.

A 294-foot well recently completed at the Hayes ranch, in the northwest corner of sec. 12, throws important light on the underground-water conditions of that region. The water rises within 55⅓ feet of the surface in the well, although in the pit it is 64½ feet below. The first water was found at 102 feet; the second at 149 feet, rising to 100 feet below the surface; the third at 169 feet,

rising to 100 feet; the fourth at 176 feet, rising to 100 feet; and the fifth at 188 feet, rising to 88 feet. This water is all in quicksand and is in moderate volume. At 212 feet water was forced up around the casing and stood within 76 feet of the surface in the pit. Water rose to 70 feet from water-bearing materials at 230 to 253 feet and to 66 feet from sand at 258 to 268 feet. At 280 to 284 feet there were two beds of sand and gravel, and this material also extended from 285 to 293 feet. The pit in which the casing is sunk is 90 feet deep, the last 6 feet in gravel. It is believed that this well contains a large volume of water, but the amount has not yet been tested.

A well in the NW. ¼ NE. ¼ sec. 22, 2 miles northeast of Carne, has tested the beds to a depth of 150 feet and found water which comes within 80 feet of the surface, but the volume is stated to be very small.

One of the wells of the Mimbres Valley Farms Co., in the NW. ¼ sec. 34, throws light on the conditions southeast of Carne. It found a large supply of water. The following record was supplied by the company:

Partial record of well in the NE. ¼ sec. 34, T. 23 S., R. 7 W.

	Feet.
Sand	51–53
Crumbly clay	53–57
Rock	57–60
Clay	60–63
Sand	63–64
Clay and bowlders	64–73
Clay	73–78
Sand and gravel	78–81
Rock	81–83
Sand	83 84
Rock and clay	84–90
Pack sand	90–94
Rock	94–96
Clay	96–98

T. 24 S., Rs. 6 and 7 W.—There are several wells along the Mimbres bottom lands south of Carne which yield supplies of excellent water in volume sufficient for extensive irrigation. The depths, however, are somewhat greater than in the tier of townships next west, for apparently part of the Mimbres underflow is dammed off by an underground ridge extending northward from the Little Florida Mountains toward and possibly connecting underground with Cooks Range. A series of test wells recently sunk by the Mimbres Valley Farms Co. in the central northern and northeastern portions of T. 24 S., R. 7 W., have found thick deposits of water-bearing beds, and most of them have yielded volumes reported as 1,000 to 1,800

gallons a minute. The water rises within 44 to 50 feet of the surface in the greater part of the area. The following records of the wells have been furnished by the company:

Partial record of well in the NW. ¼ sec. 1, T. 2¼ S., R. 7 W.

	Feet.
Sand and gravel, water bearing	48–54
Clay	54–65
Rock	65–66
Sand and gravel, water bearing	66–70
Rock	70–71
Clay and sand	71–75
Sand and gravel, water bearing	75–80
Caliche	80–82
Sand and gravel, water bearing	82–86
Rock	86–87
Sand, water bearing	87–91
Rock	91–92
Sand and gravel, water bearing	92–106
Rock	106–107
Sand and clay, water bearing	107–112
Sand and gravel, water bearing	112–140

Partial record of well in the NW. ¼ sec. 11, T. 2¼ S., R. 7 W.

	Feet.
Sand, water bearing	46–73
Clay	73–77
Sand, water bearing	77–85
Limerock	85–87
Sand and gravel, water bearing	87–93
Stone	93–95
Clay and water-bearing sand	95–110
Stiff clay	110–113
Sand and gravel, water bearing	113–123
Clay	123–156

Partial record of well in the NE. ¼ sec. 11, T. 2¼ S., R. 7 W.

	Feet.
Limy material	47–49
Sand, water bearing	49–64
Rock	64–75
Sand and gravel, water bearing	75–82
Stiff clay	82–93
Sand and gravel, water bearing	93–99
Sandy clay	99–123
Sand and gravel, water bearing	123–130

Record of well in the NW. ¼ sec. 12, T. 2¼ S., R. 7 W.

	Feet.
Soil	0–30
Sand and gravel	30–48
Sand and gravel, water bearing	48–53
Caliche	53–55

	Feet.
Pack sand, water bearing	55–57
Rock	57–60
Sand, water bearing	60–64
Bowlders and clay	64–73
Sand and stone	73–74
Sand and gravel, water bearing	74–79
Sandstone	79–81
Sand and gravel, water bearing	81–87
Limerock	87–90
Clay	90–94
Gravel, water bearing	94–99
Clay	99–101
Rock and sand	101–106

Partial record of well in the NE. ¼ sec. 12, T. 24 S., R. 7 W.

	Feet.
Clay and water-bearing sand	49–56
Sand, water bearing	56–58
Bowlders and clay	58–66
Sand and gravel, water bearing	66–68
Caliche	68–70
Sand and gravel, water bearing	70–78
Silt	78–83
Sand and gravel, water bearing	90–91
Rock	91–94
Sand and gravel, water bearing	94–101
Sand, water bearing	101–107
Joint clay	107–121
Sand and joint clay, water bearing	121–128

Partial record of well in the SW. ¼ sec. 12, T. 24 S., R. 7 W.

	Feet.
Rock	47–48
Sand and gravel, water bearing	48–58
Compact sand, some water	58–61
Rock	66–68
Sand and gravel, water bearing	68–73
Rock	73–83
Sand and gravel, water bearing	83–93
Sand and stone	93–94
Sand and stone, water bearing	94–97
Caliche	97–98
Sand and clay	98–100
Sand and gravel, water bearing	102–122

Partial record of well in the NW. ¼ sec. 13, T. 24 S., R. 7 W.

	Feet.
Clay	48–60
Caliche	60–62
Clay	62–66
Sand, water bearing	66–67
Rock	67–71
Sand, water bearing	71–73
Rock	73–74

	Feet.
Sand and clay, water bearing	74–81
Sand and rock	81–84
Sand and gravel, water bearing	84–90
Rock	90–91
Sand and gravel	91–99
Clay	99–102
Sandstone	102–103
Sand and gravel, water bearing	103–122

Partial record of well on center of north line of the SW. ¼ sec. 26, T. 24 S., R. 7 W.

	Feet.
Rock	75–76
Sand and gravel, water bearing	76–78
Rock	78–82
Clay	82–85
Rock	85–86
Sand, water bearing	86–99
Clay	99–102
Rock	102–105
Clay	105–107
Rock	107–110
Sand and clay, water bearing	110–114
Rock	114–115
Sand and clay, water bearing	115–119
Limy layer and clay	119–121
Sand, water bearing	121–130
Rock	130–131
Sand, water bearing	130–144
Joint clay	144–160

At the Sadler ranch, in the NE. ¼ NE. ¼ sec. 15, and at the Kelly ranch, in the N. ½ SE. ¼ sec. 4, T. 24 S., R. 7 W., the water is about 50 feet below the surface. At the Taber ranch, in the SW. ¼ SE. ¼ sec. 4, T. 24 S., R. 7 W., a 124-foot well has water within 47 feet of the surface. A good supply was found at 72 feet, but the water at 117 to 124 feet rose 3 feet higher. In the 80-foot well at the Kimball ranch, in the NE. ¼ sec. 4, T. 24 S., R. 7 W., the first water was found at 46 feet and the second water at 60 feet, rising to the level of the first. In a well in the north-central part of T. 24 S., R. 6 W., water was found 80 feet below the surface, and at a point about 4 miles south of that place the depth was 120 feet. A boring in the SE. ¼ sec. 7 in this township reached a depth of 200 feet without finding any water-bearing beds. In the southern part of T. 24 S., R. 7 W., the water conditions are less satisfactory, owing to small supply, the presence of quicksand, and considerable mineral matter in solution. One of the Birchfield wells, in the NW. ¼ sec. 36, is 75 feet deep and has a good volume of water rising within 71 feet of the surface, but the quality is not entirely satisfactory.

T. 23 S., R. 6 W.—A few wells sunk north and west of Myndus siding have found the water at about the same depth as in the region northeast of Carne, but the volume is less. A 92-foot well, at the Liljegren ranch, in sec. 30, all in hard clays, contained only 2 feet of water and yielded about 3 gallons a minute. An 80-foot well in the southeast corner of sec. 22 contains 5 feet of water, and though its capacity had not been ascertained at the time of the investigation it appeared not to be great. A test boring in the NW. ¼ SW. ¼ sec. 27 found a good volume at a depth of 275 feet. The water rises within 80 feet of the surface, but pumping at the rate of 250 gallons a minute lowers it to 250 feet.

LOWER MIMBRES VALLEY.

In the wide bolson east and southeast of the Florida Mountains the conditions for underground water supply appear to be unfavorable at most localities. Many test holes have been sunk to depths of 100 to 375 feet, and most of them have found quicksand yielding little or no water or water of saline character. The district is a basin into which Mimbres River spreads out as a lake in times of exceptional freshets, and here while evaporating the water deposits fine sediments. Evidently this condition has continued for a long time, as most of the materials pierced in boring are fine grained and contain saline compounds resulting from evaporation.

Several wells have been bored to various depth at the Birchfield home ranch, in the northeastern part of T. 25 S., R. 7 W. The old well, 92 feet deep, has water within 80 feet of the surface, which it is stated can be pumped at a rate of 650 gallons a minute with a drawdown of only 3 feet. The water contains much mineral matter, as shown in the analysis on page 125, but has been used satisfactorily by stock for many years. Another well recently bored to a depth of 160 feet obtains water of much better quality rising within 72 feet of the surface.

The next well, 5 miles down the valley, yields a moderate supply of fairly good water. Test wells east of this place found only salty water; others 375 and 275 feet deep, to the southwest, obtained no water or only a small amount in quicksand.

A well at one of the Birchfield ranches in the southeastern part of T. 26 S., R. 6 W., is 135 feet deep and obtains only a small volume of water, which is stated to be so strongly mineralized "that cattle have to be very thirsty to drink it."

NORTH-CENTRAL TOWNSHIPS.

In T. 22 S., R. 8 W., the bolson deposits occupy wide, shallow valleys and probably have a very irregular configuration underground.

A few wells have been sunk, some of them successful and others not. The most notable well is one in the southwestern part of the township which afforded the supply for the camp at the Fluor mine and appeared to contain a large amount of water. The depth is 220 feet and the water rises within 80 feet of the surface. It is pumped by a windmill. The well at the Wilson ranch, 3 miles northeast of the Fluor mine, is 43 feet deep and, although it affords sufficient water for cattle and stock, it pumps down with a long run of the windmill. There is an old well in the arroyo 2 miles northeast of the Fluor mine, but the yield was too small to be of much service.

NORTHEASTERN TOWNSHIPS.

Three borings have been made in the western part of T. 21 S., R. 6 W. One at the Phillips ranch, in the northwest corner of the NE. ¼ sec. 30, is 196 feet deep and yields to windmill pumping from 20 to 30 gallons a minute. Water began at a depth of 166 feet and the supply gradually increased to the bottom of the boring. Another well, 3 miles due south of this one, is 280 feet deep and yields a satisfactory supply for stock watering. Water began in this well at a depth of 266 feet. A 340½-foot boring in the southeast corner of sec. 32, 2 miles southeast of the Phillips ranch, obtained no water.

A well sunk in 1913 in the SW. ¼ SE. ¼ sec. 29, T. 22 S., R. 7 W., about 5 miles south of Florida, is 170 feet deep, the last 10 feet in water-bearing sand. No statement can be given as to the amount of water available or the height to which it rises.

A well in the northwest corner of sec. 6, T. 21 S., R. 6 W., is near the railroad and about midway between Florida and Nutt stations. It is 310 feet deep, and the water, which began at 300 feet, rises within 270 feet of the surface. This water is said to be slightly tepid.

In the valley east of the Goodsight Mountains the water supply has been tested by several wells with satisfactory results. Three of them are a short distance south of the railroad, about 6 miles southeast of Nutt. They range from 80 to 100 feet in depth and are pumped by windmills to supply water for cattle. Farther south along the valley, at a point nearly due east of Goodsight Peak, is a 110-foot well belonging to Ed Price, which appears to have an ample supply. At the ranch of Tom Hall, in the NE. ¼ sec. 3, T. 22 S., R. 5 W., there are two wells 225 feet deep in which water rises within 160 feet of the surface. Water began at 158 feet, but the volume was small until the well reached a depth of 200 feet, where coarser gravel was entered. One well is pumped with a 5-horsepower pump, which does not lower the water level noticeably. The water is used to irrigate gardens and supply a large herd of cattle. The water-bearing

beds appear to extend along the middle of this valley and to lie nearly horizontal, the increased depth to the south being due to the rise of the land. On the slopes farther east several borings from 300 to 500 feet deep failed to obtain water. To the west are rocky slopes of basalt that probably do not contain any water supplies. At Cambray the railroad company has a large dug well 269 feet deep, in which the water is 180 feet below the surface. Its capacity is about 150,000 gallons a day. The quality is fair. (See analysis, p. 125.)

SOUTHEASTERN TOWNSHIPS.

Little is known as to the water conditions in the southern part of Luna County east of longitude 107° 30′. Most of the area is underlain by sand and gravel containing some water, but the amount appears not to be large. Several wells on the Birchfield ranches, one just east of Arena and the other 6 miles northeast of Arena, obtain small supplies, but the depth of the wells and the water surface could not be learned. The railroad company has recently made a boring 504 feet deep at Arena and found no water below the main flow at 299 feet, which rose within 66 feet of the surface. The volume was found to be at least 100 gallons a minute, but the water was unsuited for locomotive use, and the well is not in service. (See analysis, p. 125.) There are old wells supplying windmills in the north-central part of T. 27 S., R. 6 W., the eastern part of the next township to the north, and 5 or 6 miles west of Birchfield, but their depths and water levels could not be ascertained. They afford water for stock.

A 72-foot well in sec. 24, T. 28 S., R. 6 W., obtained only a small supply of salty water, and the Merrifield well, 3 miles southeast, 400 feet deep, had a similar result.

WEST-CENTRAL TOWNSHIPS.

At Gage station the railroad company has two wells, one 330 feet deep with 7-inch casing and the other 340 feet deep with 10-inch casing. The water rises within 226 feet of the surface but is pumped from a depth of 265 feet. The capacity of each well is 30,000 gallons in a day of 24 hours. An analysis of the water is given on page 125. A mile and a half farther north are two windmills drawing from wells 300 feet deep in which the water rises within 270 feet of the surface. Their capabilities are not known. At Van Meter's ranch, 3 miles north of Gage, there is a 380-foot well in which the water level is 310 feet below the surface. Originally the level was higher, at about 304 feet, but it has gradually been pumped down. A windmill is used to supply the water for stock and domestic service. Four miles west of Van Meter's a boring 381 feet deep failed to obtain water. The bolsons in this region are underlain by a thick

deposit of clay with many layers of sand and gravel, but the water level is low and the supply meager. Possibly deeper wells might develop additional amounts of water. The 191-foot well at the Jordan ranch in the SW. ¼ sec. 18, T. 25 S., R. 11 W., has water within 38 feet of the surface and its capacity is estimated at 400 gallons or more. It is in the arroyo. At the Todhunter ranch, in the SW. ¼ NW. ¼ sec. 11, T. 24 S., R. 12 W., there is a well 100 feet deep supplying sufficient water for stock. It entered the water-bearing sand at 75 feet, and the water rises within 75 feet of the surface. At a ranch in the SW. ¼ NW. ¼ sec. 12, T. 25 S., R. 13 W., or nearly 6 miles farther west, there is a well 150 feet deep with the water level about 100 feet below the surface. It yields about 15 gallons a minute when pumped by windmill. The water is used for stock. A 220-foot boring made in the shallow, dry lake basin just north of the mount of rhyolite, halfway between these two ranches, obtained no water. This boring probably indicates that there are no water supplies in the slopes south of the Victorio Mountains. A 103-foot well in the W. ½ sec. 26, T. 24 S., R. 12 W., and a 116-foot well 2 miles northeast of that place failed to obtain water, but they were not sufficiently deep to reach beds in which water is to be expected. There is a well just east of Gray Butte and another one up the main draw 4 miles to the northwest, but no facts are available as to their depth or yield.

SOUTHWESTERN TOWNSHIPS.

In the wide basin lying between the Cedar Grove Mountains and the Sierra Rica there is a thick mass of bolson deposits which contain more or less water. All the tests made indicate that the water is far below the surface. In a well a mile south of Victorio station it was necessary to sink 430 feet, and the supply at that depth is not great. Six miles farther southeast, near the international boundary, is a well 320 feet deep, which yields a satisfactory supply of water for stock. At the Williams ranch, at the foot of the Cedar Grove Mountains, there is a shallow well which yields a fair amount of excellent water, probably from agglomerate. North of the Cedar Grove Mountains the water conditions vary greatly. At the Cox ranch a 165-foot well in the rock has water at a depth of 135 feet, and the supply is about 8 gallons a minute. At the Klondike ranch, near the center of T. 26 S., R. 12 W., it was necessary to sink 410 feet to obtain a very moderate supply of water, which rises within 375 to 380 feet of the surface. It is pumped by a windmill, but when this raises more than 9 gallons a minute the water level drops rapidly. In the arroyo 2½ miles west-northwest of this ranch there is a well 50 feet deep in which water rises within 40 feet of the surface, and the volume is sufficient for stock. Farther up this valley, at a point just

south of the Klondike Hills, a shallow well obtained water, b supply was inadequate. At the Bisbee watering place, in the east corner of T. 26 S., R. 11 W., the wells are 125 feet deep water within 90 feet of the surface, and yield 60 gallons a mir windmills. An unsuccessful attempt was made to develop a supply 2 miles west of Tomerlin by sinking a shaft 200 fe drifting laterally.

SPALDING REGION.

There appears to be a large supply of water in the underflow the Mimbres and for some distance on both sides in the region Spalding. At Spalding the water level is about 30 feet belc surface, and a large supply of excellent water is available. Jacobsen ranch, in the center of the SE. ¼ sec. 13, T. 21 S., R. there is a large dug well 70 feet deep, which is extensively pı for irrigation. The first water occurs at 42 feet, and a test l continued to 170 feet found the water-bearing gravel to be abo feet thick. The water rises within 38 feet of the surface, but it to 70 feet when the pump is yielding 800 gallons a minute, wl probably near the limit of the capacity of the well. A stoc with a windmill 3 miles northeast of Jacobsen's has the wate 80 feet below the surface, and another in the southeast cor sec. 9, a mile to the southeast, is 116 feet deep and has wat feet below the surface. A well in the SW. ¼ sec. 6, T. 22 S., R. is 63 feet deep with water 57 feet below the surface, and a half a mile to the northwest in the S. ½ NE. ¼ sec. 1, T. 22 S., W., is 50 feet deep and has water within 46 feet of the surface. appear to be capable of yielding good supplies. A test pit s the center of sec. 19, T. 20 S., R. 10 W., a mile north of Mimb 12 feet in diameter and 24 feet deep to bedrock. Most of the is in gravel at 19 to 22 feet. It rises within 12 feet of the s and was tested to 250 gallons a minute.

Several wells near Spalding obtain good water supplies at less than 50 feet. One 2 miles southwest of the station has within 30 feet of the surface; another 1½ miles west-southw water within 40 feet of the surface; and a third 1½ miles no of the station has water within 32 feet of the surface.

An old well in the NW. ¼ sec. 15, T. 22 S., R. 11 W of Spalding, is about 40 feet deep face, and is said to be capabl minute.

At several places in with the hope of fin

cessful. The results, however, have thrown interesting light on the deeper underground conditions. The available data from them are as follows:

The most important test of the deeper underground water in Luna County was made in 1907 at a point 2,000 feet south by east of the center of sec. 20, T. 24 S., R. 8 W., 6 miles southeast of Deming. The town of Deming contributed $4,000 toward its cost. The total depth was 1,665 feet, and a 12-inch casing was put down for 1,200 feet. Water at 520 feet rose within 17 feet of the surface, and when boring was finished a 25-horsepower pump rasing 800 gallons a minute did not lower the level greatly. Very little water was found below 520 feet, and there were many thick bodies of reddish clay all the way down.

The Burdick well, in the SE. ¼ SW. ¼ sec. 29, T. 23 S., R. 8 W., 3½ miles east of Deming, was sunk to a depth of 710 feet to test for artesian water. It is reported that a flow was found which lasted for a short time, and the water level is now 24 feet below the surface. No record of the boring was obtained, but it is said that there were many beds of sand, some with considerable water but others containing very little. In 1887 Mr. Burdick had a well sunk to a depth of 980 feet in the western part of Deming, but the result was unsatisfactory as no flow was obtained. The boring began with an 8-inch pipe and ended with a 6-inch pipe. According to a report of the driller, F. E. Hickox, "bedrock" was entered at 963 feet. Water was found at 60 feet and then at intervals of 20 to 40 feet for a considerable depth. At 773 feet it rose within 28 feet of the surface; at 836 feet, within 21 feet; at 886 feet, within 19 feet; and from 912 to 980 feet, within 9 feet of the surface, where it continued for a year, after which it dropped to 16½ feet.[1] The materials penetrated were clay, sand, "cement," and gravel in beds 5 to 18 feet thick. Several years ago a deep well was sunk at Lenark, on the Southern Pacific Railroad, about 80 miles east of Deming. It reached a depth of 950 feet, passing through the beds given on page 51. The water rises within 384 feet of the surface and is pumped at the rate of 35 gallons a minute.

At the Taylor ranch in the S. ½ sec. 6, T. 25 S., R. 9 W., 1½ miles northeast of Hondale, a deep boring found water at 202 feet and then no further supply except a very slight one at 550 feet.

At the Shay ranch, in sec. 6 (or 7), T. 28 S., R. 7 W., a boring was sunk to a depth of 975 or 1,000 feet. Water was found at intervals all the way down from 43 feet, but it came only within 15 feet of the surface.

[1] Report on artesian wells: Fifty-first Cong., 1st sess., Senate Ex. Doc. 222, p. 217, 1890.

A well 398½ feet deep 2 miles north of Columbus found but little increase in amount or head of the water below 160 feet, but the railroad well at Columbus went to a depth of 330 feet with gradually increasing supply. At Arena the railroad company has recently sunk to a depth of 504 feet in the hope of getting water for locomotives. At a depth of 299 feet water rose within 66 feet of the surface and was tested at 100 gallons a minute, but the quality was unsatisfactory.

IRRIGATION.

IRRIGATION BY UNDERGROUND WATER.

GENERAL FEATURES.

The water in the gravel and sand under the deserts of Luna County has been pumped to the surface and used for irrigation at many ranches, in general with very satisfactory results as to products and cost. The wells are mainly from 50 to 200 feet deep, and the water is pumped with small engines, mostly using naphtha for fuel and yielding from 200 to 1,000 gallons a minute. The water is in every way suitable for irrigation and its temperature averages about 65° F. Some irrigated fields are shown in Plates XI (p. 131) and XIII. Beyond a canvass of the water conditions no detailed investigation was made of the irrigation plants nor of their products. However, scattered facts were obtained as to some features of representative irrigated areas, and they will be presented in the following paragraphs.

DEMING REGION.

There are many irrigated areas about Deming, all using waters pumped from wells mostly from 40 to 200 feet deep. The Hund farm, in the northwest corner of T. 24 S., R. 8 W., is one of the best-known and most representative irrigation plants. The well is 149½ feet deep and the water level is 44 feet below the surface. The pump is in a 50-foot pit and has a 59-foot lift. It is run by a 35-horsepower engine, with a reported yield of 1,200 gallons a minute. (See Pl. X, *A*, p. 130.) A considerable variety of crops is raised, including 24 acres of beans, which, it is said, netted $2,000 in 1910.

The Shull well, in the SW. ¼ sec. 32, T. 23 S., R. 8 W., is 3 miles east by south of Deming. It is stated to be the first large well in the district. The depth is 156 feet, and the water stands within 24 feet of the surface. It is reported that a 45-horsepower gasoline engine at this well pumps 1,100 to 1,250 gallons a minute. The water is used for irrigating 170 acres, mainly of cane, potatoes, corn, beans, milo, and Kafir corn.

A. FIELD IRRIGATED BY WATER PUMPED FROM A SHALLOW WELL NEAR DEMING, N. MEX.

B. IRRIGATION IN BOLSON SOUTHEAST OF DEMING, N. MEX.

Field contains 80 acres of beans. Little Florida Mountains in distance.

The Bowman well, in the NW. ¼ sec. 12, T. 24 S., R. 9 W., 2 miles southeast of Deming, is only 52 feet deep but can furnish 350 gallons a minute, which is sufficient for about 20 acres. It is equipped with a 6-horsepower engine run by naphtha, and the consumption of that fuel is stated to be a gallon an hour. Eight acres are under ditch, comprising cane, Kafir corn, melons, pumpkins, squash, and alfalfa.

At the Hicks ranch, in the northwest corner of sec. 7, T. 24 S., R. 8 W., 3 miles southeast of Deming, there is a notably successful irrigation plant. The water is obtained from a stratum 46 to 100 feet deep and rises within 35 feet of the surface. It yields 1,200 gallons a minute. A 35-horsepower gasoline engine is used.

The Connaway well, in the NW. ¼ sec. 13, T. 24 S., R. 9 W., 3 miles southeast of Deming, was expected to provide water for the irrigation of many acres, but it is reported that the yield was only 300 gallons a minute. Its depth was 150 feet, and the water level stood 41 feet below the surface.

At the McBride ranch, near the center of sec. 12, T. 24 S., R. 9 W., 3 miles southeast of Deming, a 115-foot well furnishes water for irrigating 25 to 30 acres. The water rises within 38 feet of the surface, and the pumping capacity is stated to be about 1,500 gallons a minute. At the adjoining ranch of Bradshaw & McBride a pumping capacity of about 1,250 gallons is reported, with the water level 40 feet below the surface. The area under cultivation is about 45 acres, mainly in beans, alfalfa, and feed.

At the Ernst ranch, in the SW. ¼ sec. 9, T. 24 S., R. 9 W., 3 miles south-southwest of Deming, a 115-foot well supplies water for the irrigation of 40 acres. The water rises within 52 feet of the surface, and the yield by pumping is reported to be 1,000 gallons a minute.

At the Burdick ranch, in sec. 29, T. 23 S., R. 8 W., 4½ miles east of Deming, there is a deep well, but most of the water is derived from beds at moderate depth, with the water level 24 feet below the surface. The water is pumped with a 36-horsepower crude-oil engine, stated to yield 600 to 800 gallons a minute, and is used for irrigating 25 to 30 acres, largely in potatoes and cane. Water from the 1,665-foot well on the Burdick place 6 miles southeast of Deming is used for irrigating about 30 acres. This well is pumped to yield about 800 gallons a minute.

At the Sanders ranch, in the northwest corner of sec. 7, T. 24 S., R. 9 W., 4 miles southeast of Deming, wells 130 and 150 feet deep are reported to yield 600 gallons a minute. The water is used for irrigating 35 acres of corn and an extensive garden. The water level is about 60 feet below the surface. Several other ranches in this

vicinity irrigate small areas from wells 65 to 70 feet deep. In secs. 4, 5, and 10, T. 24 S., R. 9 W., 1½ to 2 miles southwest and southeast of Deming, wells 55 feet deep furnish water for irrigating areas of 5 to 10 acres.

At the Solignac ranch, in the southeast corner of sec. 2, T. 24 S., R. 8 W., the water is developed by a trench 40 feet long and 10 feet deep, scooped into the first water stratum, and a well 60 feet deep from which water flows when the trench is heavily pumped. The water is used for irrigating wild hay. Some features of the plant are shown in Plate XI, *A* (p. 131). It is situated in a low swale, where the water level is only 4 feet below the surface.

At the Wilson ranch, three-fourths of a mile northwest of Luxor, an 87-foot well furnishes water to irrigate an area of considerable extent. A 2-inch pump with a 7-horsepower engine working all day, with an output stated to amount to about 200,000 gallons, lowers the water only a few feet. Similar irrigation outfits have been installed at three other ranches near Luxor. About halfway between Luxor and Carne is the Russell ranch, in the northwest corner of sec. 25, T. 23 S., R. 8 W., where about 12 acres is irrigated. The pump is 4 inches in diameter and the engine 10 horsepower. The well is 105 feet deep, and the water stands about 12½ feet below the surface. It is reported that pumping 1,500 gallons a minute does not lower the water greatly.

Wells on the Glasser ranch, southwest of Carne, yield large volumes of water for irrigation. Two wells, 111 and 40 feet deep, are pumped with a No. 6 pump and a 25-horsepower engine and yield, it is said, 500 to 1,000 gallons a minute without much reduction of the water level.

HONDALE REGION.

About Hondale and southeast of that place there are several pumping plants which are irrigating areas of greater or less extent. On the ranch of J. W. Young, in the northwest corner of sec. 28, T. 24 S., R. 9 W., halfway between Hondale and Deming, there is a 203-foot well pumped by a No. 5 pump, run by electricity brought from Deming. The water rises within 55 feet of the surface, and the capacity is stated to be from 600 to 700 gallons a minute. It is used to irrigate about 80 acres of diversified crops. At the Ramsey ranch, a mile southeast of Young's, alfalfa, corn, and cane are irrigated by well water. At the R. L. Taylor ranch, 1½ miles north of Hondale, a 200-foot well, with a pump run by a 50-horsepower engine, has a capacity of about 1,200 gallons a minute. The average yield is stated to be 800 gallons, which is used for 25 acres of beans, potatoes, and forage. P. L. Rose, 1¾ miles east of Hondale, has a 75-foot well

which pumps 70 gallons a minute. An area of 7 acres is under ditch and is mostly in milo maize. At the Hines ranch, in sec. 31, T. 24 S., R. 9 W., 3 miles north of Hondale, a 57-foot well furnishes water for 4 acres of miscellaneous crops.

The Stephenson ranch, in the NW. ¼ sec. 1, T. 25 S., R. 9 W., 7 miles northeast of Hondale, pumps water from a depth of 52 feet, with a capacity stated to be about 250 gallons a minute. A 24-horsepower engine is used and is reported to consume 53 gallons of naphtha in a 36-hour run. An area of about 17 acres is under ditch, comprising 10 acres of beans, 2 acres of alfalfa, and 3 acres of feed stuff, garden truck, etc. A second well, 70 feet deep, is to be used for supplying an additional area. The Smith ranch, in the NW. ¼ sec. 3, T. 26 S., R. 9 W., 5 miles southeast of Hondale, has about 10 acres of miscellaneous crops under irrigation. The well is 161 feet deep to the third water-bearing bed, and the water rises within 42 feet of the surface. The present pumping capacity is reported to be from 300 to 500 gallons a minute. At the next ranch, three-fourths of a mile to the southeast, a well 116 feet deep furnishes water for 22 acres under cultivation. In the next section on the south several acres of corn and other crops are irrigated by well water.

Several ranches 7 miles east-southeast of Hondale have irrigation plants with small areas of flourishing crops. The water is within 37 feet of the surface. One ranch in sec. 24, T. 25 S., R. 9 W., has 2½ acres of garden.

At the Hughes ranch, in the center of sec. 15, T. 25 S., R. 10 W., an area of 25 acres is irrigated, the crops comprising cane, maize, beans, and alfalfa. The well is 160 feet deep, and the water is within 15 feet of the surface. It is reported that a No. 4 pump supplies 500 gallons a minute. With this production the water is lowered only 5 feet and then remains constant. The 25 acres can be irrigated in a three-day run of 10 hours' pumping a day. This run is repeated every 10 days during the growing season. The engine used consumes daily 20 to 25 gallons of crude oil, a fuel which costs 4½ cents a gallon at Deming.

At the G. Thompson ranch, in the NE. ¼ sec. 24, T. 26 S., R. 10 W., 80 acres is under irrigation from a 150-foot well, which has a 40-foot lift and yields 1,000 gallons a minute.

WATERLOO REGION.

There are several irrigation plants near Waterloo which give satisfactory results. The land is a smooth plain along Palomas Arroyo, and the water rises within 21 to 26 feet of the surface. The volume of water is large, so that it is not necessary to sink the wells deeper than 25 to 30 feet. Among the ranches may be mentioned that of

Peters & White, at Waterloo, on which 40 acres of wheat, oats, millet, barley, milo maize, and sorghum are under cultivation, together with some corn and garden truck. A 5-inch horizontal centrifugal pump is used with a 15-horsepower engine, consuming about a gallon of naphtha an hour, and the reported yield is 600 gallons a minute. About 3½ hours is required to wet an acre by flooding in strips 1½ rods wide and 40 rods long. At a well a short distance to the northeast a 25-horsepower engine is stated to pump 1,000 gallons a minute, which irrigates about 10 acres a day. A well 2½ miles east of Waterloo is pumped from 21 feet below the surface by an 8-horsepower engine which obtains 200 gallons a minute and in a 10-hour run consumes 6 gallons of fuel. This plant irrigates about 30 acres.

At the Snow ranches, in the NW. ¼ sec. 7, T. 27 S., R. 8 W., 100 acres is under irrigation from wells 40 and 34 feet deep, each yielding about 1,000 gallons a minute. At the White ranch, in the next section east, 30 acres is irrigated from a 37-foot well yielding 500 gallons a minute. At the Manning ranch, in sec. 1, T. 27 S., R. 9 W., 30 acres is irrigated from a 40-foot well yielding 1,000 gallons a minute. At the Laffoon ranch, near Palomas Arroyo, 5 miles southeast of Waterloo, 60 acres is irrigated from a 192-foot well having a 21-foot lift and yielding 700 gallons a minute.

At the J. H. Fowler ranch, in the NW. ¼ sec. 12, T. 26 S., R. 9 W., 40 acres is irrigated from a 40-foot well with a 500-gallon yield.

COLUMBUS REGION.

At the Bailey farm, 3 miles southeast of Columbus, water is pumped from a 185-foot well, in which the level is 2 feet below the surface, and it is reported that 2,000 gallons a minute is obtainable with the No. 6 pump used. The casing is 8¼ inches in diameter. The ordinary yield of the well is said to be 1,200 to 1,500 gallons a minute, and this consumes 0.8 gallon of naphtha an hour. About 100 acres is under cultivation, the crops comprising milo maize, wheat, oats, and alfalfa, all growing most luxuriantly.

The Pierce farm, three-fourths of a mile northeast of the Bailey pump, is irrigated from a well 250 feet deep. The principal supply, from a depth of 225 to 250 feet, rises within 6 feet of the surface. The outflow from this well is shown in Plate XII, *B* (p. 140). The yield is reported to be about 1,000 gallons a minute, with a No. 6 pump run by a 15-horsepower engine. It is stated that the engine consumes 22 gallons of naphtha every 10 hours, and this fuel has cost 13 cents a gallon delivered at Columbus. The area under cultivation is 8 acres, mainly in Kafir corn, milo maize, sweet potatoes, and alfalfa. It requires about 12 hours' pumping, or about 3 inches of water, to wet this area thoroughly.

C. B. Keenum, 2 miles south of Columbus, has a 22-foot well with the water level 12 feet below the surface. A No. 6 pump with a 20-horsepower engine is reported to furnish 1,200 gallons a minute, which is used to irrigate most of the farm of 160 acres. The crops are alfalfa, beans, and orchard fruits. It is stated that 15 gallons of naphtha, costing 11 cents a gallon, suffices for a 10-hour run.

Some other irrigated areas near Columbus are 20 acres on the Waterbury ranch; 10 acres on the De Rosear ranch, half a mile southeast of Columbus; 20 acres at the Engendorf ranch, 2 miles northeast of Columbus; 40 acres at the Gibson ranch, in the NW. ¼ sec. 35, T. 27 S., R. 8 W., from a well 40 feet deep yielding 750 gallons a minute; 10 acres at the Hunt ranch, in the southwest corner of T. 27 S., R. 7 W.; and 20 acres at the Hollock ranch, 4 miles southeast of Columbus, with a 1,800-gallon yield from a 246-foot well.

DUTY OF WATER.

There is considerable difference in the soils of the bolsons of Luna County, as they range from very sandy and porous loam to almost impervious silt, and the thickness of soil and character of the subsoil also vary widely. As the land lies nearly level the porosity of the soil is the principal factor in the duty of the water, which also varies somewhat with the crop, amount of drought, winds, degree of cultivation of the soil, arrangement and extent of ditches, and in some places the volume of water immediately available. No special attention was given to these factors, but a few general figures were supplied by the irrigators. There was considerable difference of opinion as to the amount of water required for irrigation in this region. It is probable, however, that 2½ acre-feet an acre a year will be required at most places, as this is the amount used in some other similar regions. With careful cultivation of the soil, however, a very much smaller amount will give good returns.

At one plant it was said that 70 gallons a minute, pumped 10 hours a day during the growing season, would provide for the irrigation of 10 acres; but at this rate of pumping 78 days would be required to provide 1 acre-foot over the entire 10 acres. With such light irrigation the crops should be well cultivated to conserve the moisture. At the Pierce ranch, south of Columbus, where 8 acres is under cultivation, about 2 acre-feet of water is required to each wetting, which is about 3 inches to the acre, but this is repeated several times during the season. At the Peters & White ranch, at Waterloo, 1 acre-foot of water will wet about 2½ acres at a wetting, and at a plant near by pumping 1,000 gallons of water a minute, 10 acres a day can be irrigated. At the Hughes ranch, 6 miles southwest of

Deming, a pump producing 500 gallons a minute can irrigate 25 acres in about three days, running 10 hours a day, which is a yield of nearly 3 acre-feet, or one-eighth of an acre-foot to each acre under cultivation. This irrigation is repeated every 10 days during the growing season.

COST OF PUMPING.

No attempt was made to ascertain the cost of pumping water from wells in Luna County, but a few figures were obtained incidentally during the investigation. Ordinarily in this region the engines are small—5 to 10 horsepower—the water is lifted only about 40 feet, and the volume of output ranges from 200 to 1,500 gallons a minute. The fuel used at most places is "gasoline" or "naphtha" from the Texas refineries and has cost from 11 to 15 cents a gallon at the railroad station. It is estimated that under favorable conditions 1 gallon an hour will provide for pumping 500 gallons a minute from a depth of 40 feet, which, with naphtha at 14 cents a gallon, is a fuel cost of about \$1.50 an acre-foot, or 325,850 gallons. As 2½ acre-feet an acre is usually regarded as sufficient for most crops in this region, the fuel cost on this basis would be \$3.75 an acre. The experience at several plants, however, has shown a wide range in the figures.

At the Hund well, east of Deming, the lift is 49 feet and the output is stated to be about 1,200 gallons a minute. The pump is run by a 35-horsepower engine, which is reported to consume about 35 gallons of naphtha in a 10-hour run, or 3½ gallons an hour. With fuel at 14 cents a gallon the cost of the water is \$1.21 an acre-foot. The cost of the outfit at this place is stated to be about \$3,500 (engine \$1,500, well and pump \$1,700, engine house \$200). The water from this well irrigates about 2 acres an hour for most crops, but an hour and a half is required for 2 acres of alfalfa.

At the Shull well, east of Deming, the lift is 27 feet when the pump starts, but the water gradually pumps down to 42 feet in a couple of hours. The production of 1,250 gallons a minute by a pump run by a 45-horsepower engine requires 4 gallons of naphtha an hour. The cost at this plant, with fuel at 14 cents a gallon, is \$1.43 an acre-foot. The outfit cost \$3,000, and the water will irrigate 250 acres.

At the ranch of L. Stephenson, in the NW. ¼ sec. 1, T. 25 S., R. 9 W., the pump yields 250 gallons a minute from a depth of 45 feet, with a consumption of 1½ gallons an hour. A 24-horsepower engine is used. The cost under these conditions, with naphtha at 14 cents a gallon, is \$4.20 an acre-foot.

At the Bowman ranch, in the NW. ¼ sec. 12, T. 24 S., R. 9 W., 2 miles southeast of Deming, the well is 52 feet deep, and 350 gallons

a minute is pumped with a 6-horsepower engine, which consumes 1 gallon of naphtha an hour. With fuel at 14 cents a gallon, the cost here is $2.10 an acre-foot.

At the Peters & White ranch, at Waterloo, the water is pumped from a depth of about 23 feet, and the yield is stated to be 600 gallons a minute. A 5-inch pump is used, run by a 15-horsepower engine, which consumes a gallon of naphtha an hour, and it is estimated that about 3½ hours of pumping is required to irrigate 1 acre. With naphtha costing 14 cents a gallon the cost per acre-foot of water is $1.70.

A similar well a short distance northeast of Waterloo yields 1,000 gallons a minute when pumped with a 25-horsepower engine, and it is said that this will wet 10 acres a day. A smaller plant 2½ miles east of Waterloo, lifting water from 21 feet below the surface by an 8-horsepower engine, uses 6 gallons of naphtha in a 10-hour run.

At the Hughes ranch in sec. 15, T. 25 S., R. 10 W., the water is pumped from a depth of 65 feet, yielding 500 gallons a minute, and 25 acres is now under irrigation. A No. 4 pump is used, run by a crude-oil engine, and it takes three days of pumping, 10 hours a day, to water the entire area. This wetting is repeated every 10 days during the growing season. The fuel used amounts to 20 or 25 gallons a day and costs 4½ cents a gallon, not including cost of haulage 7½ miles. This is a fuel expense of about $1 a day, 3,000 gallons of water for 1 cent, $1.09 an acre-foot, or $3 for each run to irrigate 25 acres, the cost per acre being 12 cents for each wetting. The economy in the use of crude oil for fuel is being strongly urged, and the assertion is made that the oil properly used gives as much power as gasoline. With the estimate of 8 horsepower an hour from a gallon of oil, and with oil at $2 a barrel, the cost of oil for fuel is only slightly in excess of half a cent a horsepower an hour. Gas producers using coal or oil are even more economical.

In the Columbus region the water is somewhat nearer to the surface and the pumping cost is less than in the region to the north. At the Bailey plant the production of 1,200 to 1,500 gallons an hour with water only 2 feet below the surface requires, it is said, 0.8 gallon of naphtha an hour, the cost being thus 48 cents an acre-foot. At the Pierce farm, near by, where the water is 6 feet below the surface, the pumping is done by a No. 6 pump, run by a 15-horsepower engine, requiring 22 gallons of naphtha for a 10-hour run. This is $1.68 an acre-foot with naphtha at 14 cents a gallon. At the Keenum well, 2 miles south of Columbus, the water is 12 feet below the surface and is lifted by a No. 6 pump with a 20-horsepower engine, consuming 15 gallons of naphtha in a 10-hour run. The yield is 1,200 gallons an hour, and with naphtha at 14 cents a gallon the cost of pumping is 94½ cents an acre-foot.

The following table gives a summary of some of these figures and also the cost per foot of lift per acre-foot:

Cost of pumping at irrigation plants in Luna County.

	Lift (feet).	Reported yield (gallons a minute).	Cost per acre-foot.	Approximate cost per acre-foot per foot raised.	Fuel.
Near Deming	49	1,250	$1.21	$0.025	Naphtha at 14 cents a gallon.
Do.	27-42	1,250	1.43	.036	Do.
Do.	52	350	2.10	.04	Do.
Near Hondale	[a] 45-50	250	4.20	.084	Do.
Do.	[a] 67-70	500	1.09	.015	Crude oil at 4½ cents a gallon.
Waterloo	23-25	600	1.70	.07	Naphtha at 14 cents a gallon.
Near Columbus	2-7	1,500	.48	.07	Do.
Do.	[a] 6-12	1,000	1.68	.017	Do.
Do.	[a] 12-18	1,200	.945	.055	Do.

[a] Estimated drawdowns.

According to figures compiled by the Reclamation Service, the cost of pumping in central Kansas, where liquid fuel is only moderately expensive, is about 7 cents an acre-foot for every foot the water is raised, or $3.50 for a lift of 50 feet, but this includes not only fuel but all other expenses of the pump, interest, etc.

PUMPING TESTS.

By A. T. Schwennesen.

Plan of tests.—Estimates of the yield from irrigating plants are usually based on the manufacturer's figures of the capacity of the pumps under certain ideal conditions. As such conditions seldom exist in actual practice, the yields are usually much overestimated. To obtain some reliable data in the Mimbres Valley a series of five pumping tests were made during August and September, 1913.

The plants chosen for testing represent average types, and no attempt was made to select the largest or more efficient. Thus the Baker and McBride plants are representative of the ordinary large plants, the Graham plant is a good example of one of intermediate size, and the Deane plant is an example of the smallest plants used in the district. Most of the existing plants are of the intermediate class represented by the Graham plant; few are larger in point of equipment than the Baker plant, although some very much larger yields have been reported; and very few are smaller than the Deane plant.

The discharge from the pumps was measured by a standard rectangular weir board set in the ditch. Simultaneous measurements of both the head of water on the weir and the drawdown in the well were made every 15 minutes during the test.

The principal data in regard to the pumping plants that were tested are given in the following table:

Results of pumping tests in Luna County, N. Mex.

	Baker.	Graham.	McBride.	Hollinshead.	Deane.
Depth of well...............feet..	75	67	100	....	67
Depth to water...........do....	58.5	24.8	47.1	46.9	46.3
Cost of engine....................	$1,680	$550	$1,000	....	....
Cost of pump....................	$250	$110	$608	....	....
Cost of well.......................	$1,145	$278	....	....	....
Total cost of plant................	$3,075	$928	....	....	....
Duration of test..........hours..	1⅝	1½	1¼	1½	1¾
Maximum discharge measured gallons a minute..	898	558	518	178	156
Average discharge.........do....	603	555	444	166	122
Maximum drawdown.......feet..	10.2	11.0	27.6	12.3	8.8
Average discharge lift.....do....	58.6	22.6	69.0	50.8	54
Average suction lift.........do....	15	14.3	9.7	11.4	2.8
Average total lift..........do....	73.6	36.9	78.7	62.2	56.8
Effective horsepower [a]...........	11.2	5.18	8.83	2.62	1.75
Rated horsepower................	40	12	32	11	7
Efficiency [b]...........per cent..	28.1	43.2	27.6	23.8	25.0
Specific capacity of well [c]........	88.0	50.7	18.8	14.5	17.7
Fuel:					
Kind........................	Distillate.	Distillate.	....	Distillate.	Crude oil.
Cost per gallon.......cents..	6½	9½	....	9½	5½
Amount used.....gallons an hour....................	2½	1	....	....	....
Cost of fuel per acre-foot of water pumped........................	$1.46	$0.93	....	....	....
Cost of fuel per acre-foot of water lifted 1 foot.............cents..	2	2½	....	....	....

[a] Effective horsepower $= \frac{\text{pounds of water pumped per minute} \times \text{total lift in feet}}{33{,}000}$.

[b] Efficiency $= \frac{\text{effective horsepower}}{\text{rated horsepower}}$.

[c] Specific capacity is the yield (in gallons a minute) per foot of drawdown.

Baker plant.—The plant of C. L. Baker, in the SW. ¼ SE. ¼ sec. 4, T. 24 S., R. 9 W., is equipped with a 40-horsepower engine manufactured by the Bessemer Gas Engine Co., of Grove City, Pa. It is designed to burn crude oil and the cheaper grades of distillate. The pump is a Blackham-Scale single-stage horizontal centrifugal pump with a 19-inch runner. The pump is set 53 feet below the ground surface and connected with the engine through a vertical shaft and belt.

The well is dug 75 feet deep. It was originally bored 115 feet deeper, but the bored part was afterward filled in. For the first 52 feet the well is 9 by 9 feet in cross section, for the next 18 feet it is 5 by 5 feet, and for the last 5 feet it is 4 by 4 feet. It is curbed from top to bottom with planks. No complete log of the well was obtained, but the owner stated that the materials passed through were yellow clay and gravels in alternate layers. The clay beds averaged about 10 feet in thickness and the interbedded gravels from 1 to 4 feet. Two gravel beds near the bottom, separated by 12 feet of clay and sand, furnish most of the water. The cost of the well as given by the owner is as follows:

Constructing 75 feet of dug well.........................	$800
Boring 12-inch hole, 115 feet, at $1.........................	115
Casings, 12-inch, 115 feet, at $2.........................	230
	1,145

The cost of the dug part of this well was excessive, and ordinarily a well of this kind costs much less.

This plant irrigates about 30 acres. The principal crops are alfalfa and beans. Five cuttings of alfalfa a year, yielding from 1¼ to 1½ tons an acre a cutting, are usually obtained. Each crop requires two waterings. From 6 to 7 acres of alfalfa can be irrigated during a 10-hour pumping day.

Graham plant.—The plant of J. M. Graham, at the southwest corner of sec. 11, T. 24 S., R. 8 W., is equipped with a 12-horsepower Fairbanks-Morse engine, belted to the vertical shaft of a single-stage horizontal American centrifugal pump set at the bottom of a 22-foot pit. The engine is designed to burn gasoline and the higher grades of distillate.

The depth of the well is 67 feet, of which the first 22 feet is dug 9 by 5 feet in cross section and the remaining 45 feet bored 22 inches in diameter. The dug part is curbed with pine lumber, and the bored part is cased with perforated casing. The owner reports the following log for the well:

Log of well in the northwest corner of sec. 11, T. 24 S., R. 8 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Mostly clay with some thin beds of sand and caliche	56	56
Medium to coarse water-bearing gravel	11	67

The cost of constructing the well was as follows:

Digging pit, 22 feet at $3	$66.00
Lumber for curbing	10.00
Boring 22-inch hole, 45 feet at $2.50	112.50
Casing, 22-inch, 45 feet at $2	90.00
	278.50

This plant furnishes water for 10 acres of alfalfa.

McBride plant.—The equipment of the plant of M. L. McBride in the NW. ¼ SW. ¼ sec. 30, T. 24 S., R. 8 W., consists of a 32-horsepower Fairbanks-Morse engine using crude oil and the cheaper grades of distillate. A No. 5 Layne & Bowler pump is set 65 feet below the surface and connected to the engine at the surface through a belt and vertical transmission shaft. The pump, with 20 feet of 7⅝-inch suction pipe and 70 feet of 8⅝-inch discharge pipe, cost $608.50 f. o. b. at Deming.

Three water-bearing beds were penetrated in the well in a total depth of approximately 100 feet. The following log was furnished by the owner:

Log of well in the NW. ¼ SW. ¼ sec. 30, T. 24 S., R. 8 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, and sand	64	64
Gravel and sand, water bearing	6	70
Clay	2	72
Sand with some gravel, water bearing	10	82
Clay and sand	18	100
Gravel, water bearing	(?)	(?)

The plant irrigates 20 acres of beans and 5 acres of maize. The beans are watered three times during the growing season of 4 months. One watering takes from 75 to 90 hours of continuous pumping.

Hollinshead plant.—The plant of M. W. Hollinshead, in the NE. ¼ NE. ¼ sec. 10, T. 26 S., R. 10 W., is equipped with an 11-horsepower Foos engine burning gasoline and the better grades of distillate. The pump is a single-stage centrifugal pump set at water level in a pit and connected to the engine at the surface by a belt and vertical shaft. The well consists of a dug pit 47 feet deep and curbed with lumber. From the bottom of the pump pit the well is bored and cased with perforated casing.

The plant irrigates 20 acres of beans, Indian corn, and milo maize.

Deane plant.—The plant of E. S. Deane, at the northwest corner of the SE. ¼ sec. 2, T. 24 S., R. 9 W., is run by a 7-horsepower Simple engine, manufactured at Trinidad, Colo. Crude oil and the cheaper grades of distillate are used for fuel. The pump is a Buffalo No. 2 single-stage centrifugal pump with a 12-inch runner. It is set at the bottom of a 53-foot pit and connected with the engine through a vertical shaft and belt. The well is 67 feet deep and contains one water-bearing bed. From the bottom of the pit a 15-inch hole cased with perforated casing extends down for 14 feet. The following log was reported:

Log of well in the SE. ¼ sec. 2, T. 24 S., R. 9 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay with some caliche	65	65
Water-bearing gravel	2	67

This plant is operated in connection with a small earth reservoir and furnishes water for 5 to 8 acres of alfalfa, melons, and garden truck.

PUMPING IN RIO GRANDE VALLEY.

In 1904 Slichter[1] made some careful tests of the amounts of fuel required to run pumping plants in the Rio Grande valley; and as the conditions there are somewhat similar to those in the Deming region, a summary of the results is given in the following table:

Fuel cost of pumping at some wells in Rio Grande valley.

Depth of well (feet).	Lift (feet).	Yield (gallons a minute).	Gasoline used (gallons an hour).	Cost.[a]	
				Per 1,000 gallons.	Per acre-foot.
30	28	258	0.5	$0.004	$1.35
66	31	269	.8	.006	1.93
60	41½	1,325	2.5	.00375	1.22
60	36	658	1.4	.0045	1.48
48	45½	131	.5	.009	3.20
58	27	648	1.08	.003	1.04
52	40½	725	2	.0055	1.78
52	40	[b] 658	1	.0028	.95
63	35	325	1.8	.0113	3.63
59	36	271	1.5	.0106	3.40

[a] Costs are recalculated on basis of gasoline at 12 cents a gallon.
[b] Alfalfa irrigation, three wettings, 7 days apart, 16 hours' run for each. The amount required was 3 inches, which cost $2.02 an acre, and the crops averaged 1 ton to the acre.

The cost of pumping by electricity was obtained at one plant where the well is 68 feet deep, the water is lifted 39 feet, and the yield is 378 gallons a minute. The production was reported to be 134,400 foot-gallons of water to the kilowatt hour of current, and the total cost $5.75 an acre-foot with power at 5 cents a kilowatt-hour. A crude-oil gas generator working a No. 6 pump with 37-foot lift and a yield of 938 gallons a minute cost 0.9 cent a thousand gallons, or 70 cents an acre-foot, with oil at 3 cents a gallon, and the same pump run with gasoline at 12 cents a gallon cost $2.52 an acre-foot. There was about 20 per cent advantage in running all night, and storage reservoirs are an important economy.

IRRIGATION BY SURFACE WATER.

At present practically no surface water is used for irrigation in Luna County. Ditches have been constructed at several places to take water out of the Mimbres during flood stages, and they have conveyed some water into a few sections. The Rio Mimbres Land Co. has a project of building a dam in the narrows in sec. 1, T. 20 S., R. 10 W., to store flood waters of the river. The topographic conditions are favorable, for at the dam site the valley is narrow and in rock, but just above this place it widens into a broad basin which would make a reservoir approximately 2 square miles in area.

[1] U. S. Geol. Survey Water-Supply Paper 141, pp. 34–35, 1905.

This would be filled by the flow of the river, mainly at times of flood. The ditches leading out on the west bank would extend past Faywood Springs and Faywood station and thence south near the west line of R. 11 W. The eastern ditch would pass behind the old village of Mimbres through the middle of R. 10 W. to and through the southeast corner of T. 22 S., R. 10 W. The area served by these ditches north of the Southern Pacific Railroad would be about six townships, or more than 200 square miles. The catchment area of the Mimbres basin above the dam has been estimated at 600 square miles, and with rainfall varying from 20 inches on the Black Mountains to about 12 inches in the foothills a total volume of 500,000 acre-feet a year is indicated. There is, however, a very large loss by evaporation and other causes, for the gagings from 1908 to 1913 at the dam site, as explained on page 112, have shown only from 3,270 to possibly 30,000 acre-feet a year, and the average is considerably below 10,000 acre-feet. This would provide water for irrigating only about 5,000 acres, or less than 38 quarter sections, with the duty of water at 2 feet. Even this does not allow for loss by reservoir evaporation and leakage from ditches, which would probably amount to 50 per cent.

Another project that has been contemplated is to dredge out the depression of Florida Lake to tap the underflow and then to convey this water in ditches leading east and south into a wide area northeast of the Little Florida Mountains.

ELEVATIONS.

On Plate I (in pocket) the topography of Luna County is shown by contour lines spaced 200 feet apart vertically, with sea level as the datum. Each line indicates the altitude along its course, and from the distances between the lines the general rates of slope can be inferred. With a 200-foot contour interval, however, features less than 200 feet above the adjacent country and minor changes of slope are not shown. The contours shown by full lines are condensed from the map of the Deming quadrangle much of which is accurately surveyed. Those shown by broken lines are based on determinations of altitude by barometer compared with many elevations given in railroad profiles, level lines of the United States Geological Survey, the International Boundary Survey, and some recently established stations of the United States Coast and Geodetic Survey.

A knowledge of precise elevations in the bolson areas of Luna County is of great importance in the study of the altitudes or grade of the underground water. These altitudes should be recorded and as wells become numerous comparisons should be made from time to time to ascertain the effect of heavy pumping, possibly with a view of so restricting excessive draft as to prevent final depletion of the supply. In order to determine water levels it is necessary to utilize

all available accurate data as to elevations of the land, and accordingly in the following pages are given those which are now established as compiled from various sources.

UNITED STATES GEOLOGICAL SURVEY.

The following list gives the results of precise leveling along the Atchison, Topeka & Santa Fe Railway from Rincon to Silver City by M. S. Bright, of the United States Geological Survey, in 1905. They are tied to a line run in 1905 to 1907 from Yuma to Deming, but are not otherwise adjusted.[1]

	Feet.
Hockett, 50 feet west of track, 5 feet south of milepost 1094, in front of section house; iron post stamped "195"	4, 512. 278
Hockett, 3 miles south of, 45 feet west of track, 5 feet north of milepost 1097; iron post stamped "198"	4, 483. 521
Hockett, 6 miles south of, 40 feet east of track, opposite milepost 1100; iron post stamped "201"	4, 491. 682
Easley, in front of sign board; top of rail	4, 516. 13
Easley, 2 miles west of, 75 feet north of track, 30 feet east of milepost 1103; iron post stamped "204"	4, 607. 728
Nutt, 260 feet south of station, 234 feet south of south rail in main line, 40 feet east of gate near wire fence, in concrete; iron post stamped "206"	4, 718. 486
Nutt, 260 feet south of station, 234 feet south of south rail on main line, 40 feet east of gate near wire fence, set in cement 4 inches from above bench mark; aluminum tablet stamped "206"	4, 717. 963
Nutt, 3 miles south of, 165 feet south of milepost 1108, 45 feet west of track, 6 feet north of telegraph pole; iron post stamped "208"	4, 652. 021
Nutt, 6 miles south of, 45 feet west of track, 4 feet south of milepost 1111; iron post stamped "211"	4, 610. 256
Nutt, 9 miles south of, 45 feet west of track, 6 feet north of milepost 1114; iron post stamped "214"	4, 583. 268
Nutt, 12 miles south of, 45 feet west of track, 6 feet north of milepost 1117; iron post stamped "217"	4, 523. 648
Florida, in front of sign board; top of rail	4, 505. 32
Florida, 2 miles south of, 45 feet west of track, 6 feet north of milepost 1120; iron post stamped "220"	4, 482. 705
Florida, 5.2 miles south of, about 0.25 miles south of milepost 1123, at north end of cut, 80 feet east of track, 12 feet west of wagon road, near wire fence; iron post stamped "223"	4, 411. 703
Mirage siding; top of rail	4, 377. 53
Mirage siding, 3 miles south of, 45 feet west of track, 6 feet north of milepost 1129; iron post stamped "229"	4, 332. 711
Deming, 210 feet north of second switch block in station, Atchison, Topeka & Santa Fe Railway yards, then 100 feet east of main line, 200 feet southeast of milepost 1132, at fence corner; iron post stamped "232"	4, 325. 157
Deming, in front of Atchison, Topeka & Santa Fe Railway station; top of rail	4, 335. 553
Deming, in front of Southern Pacific Railroad station; top of rail	4, 335. 81
Deming, at southwest corner of Silverton and Railroad avenues, at corner of concrete sidewalk, in concrete; iron post stamped "233"	4, 334. 928

[1] Later work by the United States Coast and Geodetic Survey has shown that they are 0.97 foot too low.

	Feet.
Deming, city waterworks, 222 feet south of Southern Pacific Railroad track, in northwest corner of foundation stone; aluminum tablet stamped "234"	[1] 4,345.802
Deming, 3 miles northwest of, 45 feet north of track, 6 feet east of milepost 1136; iron post stamped "236"	4,376.552
Deming, 6 miles northwest of, 90 feet northeast of track, 50 feet northeast of wagon road, 30 feet northeast of milepost 1139; iron post stamped "239"	4,451.165
Deming, 9 miles northwest of, 75 feet northeast of track, 35 feet northeast of milepost 1142 and wagon road; iron post stamped "242"	4,530.022
Deming, 12 miles northwest of, 90 feet northeast of track, 45 feet northeast of milepost 1145 and wagon road; iron post stamped "245"	4,610.191
Deming, 15 miles northwest of, five telegraph poles west of milepost 1148, 80 feet north of bridge 4, at fence corner; iron post stamped "248"	4,672.429
Spalding, in front of signboard; top of rail	4,728.01
Spalding, 0.5 mile northwest of, 75 feet north of track, 30 feet north of milepost 1151; iron post stamped "251"	4,738.973
Spalding, 3.5 miles northwest of, 45 feet north of milepost 1154, 5 feet north of wagon road; iron post stamped "254"	4,806.387
Faywood, 340 feet east of station, 45 feet north of road crossing, seven telegraph poles west of milepost 1157; iron post stamped "257"	4,910.751
Faywood, in front of station; top of rail	4,914.47
Faywood, 3 miles west of, 95 feet south of milepost 1160, 55 feet south of track, 30 feet north of wagon road; iron post stamped "260"	5,000.982
Faywood, 6 miles west of, 110 feet south of milepost 1163, 70 feet south of track, 1 mile east of Whitewater, 18 feet north of wagon road; iron post stamped "163"	5,128.36
Whitewater, in front of station at milepost 1164; top of rail	5,156.77
Whitewater, 700 feet northwest of station, 85 feet south of junction of Silver City-Deming and Whitewater-Hanover roads, 21 feet south of wagon roads, in limestone rock; aluminum tablet stamped "264-B-1905"	5,157.825
Whitewater, 3 miles northwest of, 500 feet east of milepost 1167, 65 feet north of bridge 23, on point of ridge; iron post stamped "267-B-1905"	5,210.045

The following list gives the results of precise leveling along the Southern Pacific Railroad from Deming to the west line of Luna County, connected with a line of levels brought from Yuma but otherwise not adjusted.[2] The work was done in 1906–7 by A. R. Carver and W. A. E. Hult, of the United States Geological Survey.

	Feet.
Milepost 1203, 100 feet south of, 20 feet north of wagon road; iron post stamped "4-C-1906"	4,382.608
Parma, opposite milepost 1202; top of rail	4,393.4
Parma, 2 miles west of, 100 feet south of milepost 1200, 50 feet north of wagon road; iron post stamped "7-C-1906"	4,410.588

[1] U. S. Coast and Geodetic Survey gives 4,346.77 feet.
[2] According to the latest data 0.97 foot should be added.

	Feet.
Tunis, in front of signboard; top of rail	4, 423. 8
Tunis, 1¼ miles west of, 100 feet south of milepost 1197, 15 feet north of wagon road; iron post stamped "10–C–1906"	4, 434. 155
Tunis, 4¼ miles west of, 75 feet south of milepost 1194, 20 feet north of wagon road; iron post stamped "13–C–1906"	4, 422. 177
Mongola, in front of signboard; top of rail	4, 430. 2
Mongola, 0.9 mile west of, 100 feet south of track, 15 feet north of wagon road, 75 feet south of milepost 1191; iron post stamped "16–C–1906"	4, 435. 946
Gage, 1 mile east of, 110 feet south of track, 15 feet north of road, 75 feet south of milepost 1188; iron post stamped "19–C–1906"	4, 479. 401
Gage, in front of; top of rail	4, 489. 2
Gage, 2 miles west of, 100 feet south of track, 30 feet north of wagon road at grade crossing; iron post stamped "22–C–1906"	4, 530. 170
Aitkin (now Quincy), in front of signboard; top of rail	4, 563. 8
Aitkin (now Quincy), 40 feet north of wagon road, 75 feet south of milepost 1182; iron post stamped "25–C–1906"	4, 560. 536

UNITED STATES COAST AND GEODETIC SURVEY.

In 1910 a network of primary triangulation was extended across Luna County by the United States Coast and Geodetic Survey. Cooks Peak, the Florida Mountains, and other high points were occupied, and the observers measured a very precise base line passing through Deming. The results give accurate determinations of latitude, longitude, and altitude of various points which are briefly described in the following paragraphs. More detailed descriptions are given in the Coast Survey report.[1]

Stations established by United States Coast and Geodetic Survey in Luna County, N. Mex.

Name.	Latitude.			Longitude.			Elevation.	
	°	′	″	°	′	″	*Meters.*	*Feet.*
Cooks Peak	32	32	9. 548	107	43	52. 419	2, 562. 9	8, 408. 45
Florida	32	7	1. 834	107	37	36. 040	2, 145. 0	7, 037. 39
Hermanas	31	48	11. 577	107	56	52. 331	1, 611. 0	5, 285. 42
Red [Mountain]	32	13	. 806	107	53	31. 665	1, 651. 4	5, 417. 97
Deming, south base	32	3	. 447	107	50	14. 406	1, 280. 4	4, 200. 78
Deming, north base	32	10	19. 489	107	45	21. 268	1, 301. 0	4, 268. 36
Deming, city waterworks	32	16	10. 606	107	46	1. 390	*1, 324. 9	[b] 4, 346. 77
Near [Sierra Rica]	31	47	23. 753	108	11	3. 844	1, 649. 4	5, 411. 41
Boundary monument 31, top of masonry base	31	47	1. 169	107	55	45. 394	[a] 1, 437	4, 714. 56
Boundary monument 32, top of masonry base	31	47	1. 200	107	57	18. 025	*1, 495	4, 904. 85
Boundary monument 39, top of masonry base	31	47	1. 260	108	11	11. 468	1, 534. 2	5 033. 45
Boundary monument 40, top of masonry base	31	47	1. 265	108	12	29. 563	*1, 501. 4	4, 925. 84
Black Mountain (cairn)	32	19	59. 0	107	53	1. 10	[a] 1, 638. 7	5, 376. 30
Cone [Victorio Peak]	32	12	2. 71	108	6	32. 8	1, 510. 4	4, 955. 37

[a] Not checked.
[b] United States Geological Survey gives 4,345.802 feet.

The elevations marked * were determined by spirit leveling by other surveys, and the error is believed to be not more than 2 inches. The elevation at the Deming waterworks is that of bench mark 234,

[1] Bowie, William, The Texas-California arc of primary triangulation: U. S. Coast and Geodetic Survey Special Pub. 11, 1912.

established by the United States Geological Survey, and this was used as a datum after adding 0.97 foot to accord with the elevation at El Paso. The possible error in the other elevations, determined by reciprocal vertical angles, range from 4 to 35 inches. The elevation given for the top of the masonry base of monument 31 is not deduced from reciprocal angles and may have an error of several feet. The international boundary survey gives 1,433.5 meters for this monument, with a possible error of 1 meter, 1,487.8 meters for monument 32, 1,518.4 meters for monument 39, and 1,494.2 meters for monument 40, all determined by spirit levels along the boundary line. Black Mountain and cone [Victorio Peak] were measured by angles from the two Deming bases. The elevation stations are as follows:

Cooks Peak: Summit marked by brass disk having for reference mark a cross cut in rock about 35 feet away.

Florida: On a flat-topped knob in a saddle about midway between the high rock peak to the north and the round-top peak to the south, about 500 yards south of the highest rock peaks at the north end of the Florida Mountains. Station marked by a brass disk having for reference mark a cross cut in rock about 15 feet away.

Hermanas: On the highest one of four summits of the Carrizalillo Hills 3 miles S. 5° E. from Hermanas, marked by a brass disk having for reference mark a cross cut on large bowlder about 35 feet away.

Red: Marked by brass disk, about 20 paces, a little north of east of highest point of Red Mountain.

Deming, south base: About 15 miles southwest of Deming, 1 mile S. 85° E. from Midland station, on F. W. Schweiyer's ranch, 1¾ miles N. 75° E. from ranch house and windmills of R. W. Yeargins. The place is marked by a brass cap on a 3-inch iron pipe set in the top of a cylinder of concrete 20 inches in diameter and 24 inches long, set flush with the ground. There is also an underground mark set in a concrete column and a reference mark a short distance southeast.

Deming, north base: About 6 miles south of Deming, near the center of sec. 34, T. 24 S., R. 9 W. It is marked in same manner as the south base, with reference mark about 50 feet distant a little east of north.

Near: On the easternmost limestone peak, 1 mile west-northwest of the International mine, 5 miles S. 33° W. from Victorio station, marked by brass disk set in rock having for reference mark a cross cut in rock about 13 feet southeast.

Boundary monuments: Nos. 39 and 31 are iron monuments on the international boundary; No. 32 is a stone monument 4 miles south of

Hermanas, on the highest point of the boundary line, where it crosses the Carrizalillo Hills; and No. 40 is at the angle where the boundary turns to the south, 2½ miles west of the International mine.

Deming waterworks: High red tank in northwestern part of Deming, with United States Geological Survey bench mark 234 a short way south, which, with 0.97 foot added, is used to control the vertical-angle elevations of all the triangulation stations in this vicinity.

RAILROAD PROFILES.

Leveling by the Southern Pacific Co. has given the following elevations at points from Cambray to Deming. (For Deming to Quincy, see United States Geological Survey levels, pp. 174–176.)

	Feet.
Cambray	4,225.0
Akela	4,168.3
Myndus	4,149.3
Carne	4,188.73
Luxor	4,273.98
Deming station (U. S. G. S. 4,335.81)	4,331.95

In the following list of elevations along the El Paso & Southwestern Railroad in Luna County the figures are those given by the company and are not adjusted. The level line begins in the station at El Paso, with an initial altitude of 3,714.6 feet (3,724 feet according to the United States Geological Survey, and about 3,726 feet according to the Coast and Geodetic Survey).

	Feet.
Dona Ana-Luna County line	4,142
Arena station	3,953
Milepost 66	3,980
Milepost 70	3,999
Milepost 71	4,001
Milepost 72	4,001
Milepost 73	4,027
Columbus station	4,054
Summit one-half mile east of Mimbres	4,341
Mimbres station	4,340
Valley bottom 6½ miles west of Mimbres	4,215
Hermanas station	4,448
Carrizalillo Spring (water surface)	4,515
Summit at milepost 97	4,594
Victorio station	4,568
Grant-Luna County line	4,693

The following elevations along the Deming branch of the El Paso & Southwestern Railroad were taken from a profile prepared by the company:

	Feet.
Deming yards, joining Southern Pacific R. R.	[1] 4,350.00
Milepost 123 from El Paso (down grade south)	4,334.55
Milepost 122	4,332.02
Milepost 121	4,327.83
Milepost 120	4,319.50
Milepost 119	[2] 4,314.00
Milepost 118	4,300.61
Milepost 117	[2] 4,290.50
Milepost 116	[2] 4,284.00
Milepost 115	[2] 4,267.00
Hondale (114.94 miles)	4,266.93
Milepost 114	[2] 4,251.00
Milepost 113	[2] 4,235.00
Milepost 112	4,227.90

[1] About 5 feet lower than the elevation given by the United States Coast and Geodetic Survey.

[2] Interpolated from near-by points.

	Feet.
Milepost 111	[1] 4, 211. 00
Milepost 110	4, 209. 01
Milepost 109	[1] 4, 195. 00
Midway (108.96 miles)	[1] 4, 194. 00
Arroyo crossing (foot of grade)	4, 190. 99
Milepost 108 (up grade south)	[1] 4, 199. 00
Milepost 107	[1] 4, 204. 00
Milepost 106	[1] 4, 217. 26
Milepost 105	[1] 4, 225. 00
Milepost 104	[1] 4, 238. 75
Milepost 103	4, 266. 62
Tomerlin (102.65 miles)	[1] 4, 272. 00
Milepost 102	[1] 4, 300. 00
Milepost 101	4, 330. 70
Milepost 100	[1] 4, 355. 00
Milepost 99	[1] 4, 362. 00
Milepost 98	4, 382. 02
Milepost 97	4, 382. 02
Milepost 96	4, 390. 02
Milepost 95	[1] 4, 400. 00
Milepost 94	[1] 4, 438. 00
Hermanas (93.41 miles)	4, 448. 65

LEVEL LINE FROM DEMING ALONG GRADE ROAD TO MEXICAN BOUNDARY.

In the spring of 1913 a line of levels was run by R. C. Seitz from the Santa Fe Railway station at Deming to and along the grade road to the international boundary and joined to boundary monument 23. It was also tied to the "north base" of the Coast and Geodetic Survey, and the figures given below are reduced to that datum by distributing a discrepancy of 1.56 feet between that place and Deming station. The elevation of Deming station is given as 4,335.553 feet by the United States Geological Survey, and a correction of 0.97 foot is added to bring it into accord with the Coast Survey figure for the United States Geological Survey bench mark at the waterworks. At the south end the tie to monument 23 is very close, where 13 feet is added to the Boundary Commission's determination, 4,000.65 feet. This figure (13 feet) is the mean discrepancy found by the United States Geological Survey at El Paso and in southern Arizona, and if it is correct it indicates that the level line down the grade road tied 2.34 feet too high. This 13-foot correction is not very useful, however, for the Coast Survey determinations of altitude of monuments 32, 39, and 40 indicate much higher figures. Therefore in the following table it will be assumed that the level line by Mr. Seitz is correct from "north base" to monument 23 with the altitude of the latter at 4,015.94 feet:

	Feet.
Deming (Atchison, Topeka & Santa Fe Railway depot), top of rail	4, 336. 5
Grade road at crossing of railway tracks	4, 335. 0
Line between T. 23 S. and T. 24 S	4, 318. 8
Corner of secs. 2, 3, 10, and 11, T. 24 S., R. 9 W	4, 309. 6
Corner of secs. 10, 11, 14, and 15	4, 301. 2
Corner of secs. 14, 15, 22, and 23	4, 295. 2
Line between secs. 23 and 26	4, 280. 5
Line between secs. 26 and 35	4, 267. 3

[1] Interpolated from near-by points.

	Feet.
"North Base," near center of SE. ¼ sec. 34	4, 268. 4
Line betwen T. 24 S. and T. 25 S	[1] 4, 253. 5
Corner of secs. 1, 2, 11, and 12, T. 25 S., R. 9 W	4, 243. 5
Line between secs. 12 and 13	4, 233. 9
Line between secs. 13 and 24	4, 222. 5
Line between secs. 24 and 25	4, 218. 0
Bottom of grade in east-central part of sec. 25	4, 216. 5
Line between secs. 30 and 31, T. 25 S., R. 8 W	4, 228. 0
Top of grade, west-central part of sec. 31	4, 241. 0
Line between T. 25 S. and T. 26 S	4, 239. 5
Line between secs. 1 and 12, T. 26 S., R. 9 W	4, 236. 4
Line between secs. 7 and 18, T. 26 S., R. 8 W	4, 217. 5
Line between secs. 18 and 19	4, 183. 5
Line between secs. 19 and 30	4, 162. 8
Line between secs. 30 and 31	4, 148. 7
Line between T. 26 S. and T. 27 S	4, 131. 1
Line between secs. 5 and 8, T. 27 S., R. 8 W	4, 118. 8
Line between secs. 8 and 17	4, 112. 5
Palomas Arroyo (bottom)	4, 102. 5
Line between secs. 17 and 20	4, 154. 0
Corner of secs. 20, 21, 28, and 29	4, 182. 5
Line between secs. 28 and 33	4, 000. 5
Line between T. 27 S. and T. 28 S	4, 204. 5
Top of grade near center of sec. 4, T. 28 S., R. 8 W	4, 205. 5
Line between secs. 4 and 9	4, 205. 3
Corner of secs. 9, 10, 15, and 16	4, 196. 2
Line between secs. 15 and 22	4, 176. 5
Line between secs. 22 and 27	4, 123. 2
Line between secs. 27 and 34	4, 088. 0
Columbus station	[2] 4, 063. 3
Line between T. 28 S. and T. 29 S	4, 037. 7
Line between secs. 2 and 11, T. 29 S., R. 8 W	4, 003. 0
Line between secs. 11 and 14	3, 991. 1
International boundary	3, 997. 1
Monument 23	4, 014. 2

ELEVATIONS OF MONUMENTS ALONG INTERNATIONAL BOUNDARY.

In the final survey of the boundary between Mexico and the United States a spirit-level line was run and elevations of the boundary monuments and other points near by were determined with precision. A topographic map published with the report of the Boundary Commission shows the topography by contour lines with 20-meter intervals in a narrow zone along the line, and the following list of elevations of monuments is printed in the report. The elevations were given in meters and represent the tops of the masonry bases of the

[1] Iron post near this point is marked "4254."
[2] Railroad profile gives 4,054 feet.

monuments. As a portion of the line was run before the monuments were set there are possible errors in some of the figures, as shown by the footnotes. The line began at the bench mark of the Southern Pacific Railroad at El Paso, which was later, when the level line reached the Coast Survey bench mark at San Diego, found to be marked 2.62 meters too high. Apparently from the statement in the report the elevations are reduced to mean tide level at San Diego. In the Coast Survey work in this area vertical angles were taken to and from monuments 32, 39, and 40, which were found to be respectively 23.6, 51.8, and 23.6 feet higher in altitude than the figures given by the commission. Monument 31 was sighted and found to be about 19 feet higher. The Coast Survey also found monument 2, near El Paso, to be given as 12.47 feet too low, and the United States Geological Survey found at monuments 1, 3, 88, and 92 elevations averaging 13 feet higher than those given by the Boundary Commission.

Elevations of monuments on international boundary along Luna County line.

No.	Elevation.		Possible error (meters).	No.	Elevation.		Possible error (meters).
	Meters.	Feet. [a]			Meters.	Feet. [a]	
14	1,319.3	4,328.40	0.5	28	1,306.0	4,284.77	
15	1,280.1	4,199.79		29	1,272.6	4,175.19	0.5
16	1,269.7	4,165.67	1.0	30	1,271.7	4,172.23	
17	1,202.6	3,944.22	.5	31	[b] 1,433.5	4,702.42	1.0
18	1,205.6	3,955.04		32	[c] 1,487.8	4,881.22	
19	1,208.4	3,964.56		33	1,387.6	4,552.48	
20	1,211.0	3,973.09		34	1,387.2	4,551.17	
21	1,213.1	3,979.98		35	1,346.2	4,416.65	.5
22	1,212.9	3,979.32		36	1,347.2	4,419.93	
23	1,219.4	4,000.65		37	1,384.7	4,542.97	
24	1,259.3	4,131.55		38	1,458.8	4,786.08	2.0
25	1,297.7	4,257.54	1.0	39	[d] 1,518.4	4,981.62	2.0
26	1,315.8	4,316.92		40	[e] 1,494.2	4,902.22	
27	1,294.8	4,248.02					

[a] United States Geological Survey elevations at El Paso and west are 13 feet higher.
[b] Coast and Geodetic Survey gives 1,437.0 meters; may be a few meters in error.
[c] Coast and Geodetic Survey gives 1,95.0 meters.
[d] Coast and Geodetic Survey gives 1,534.2 meters.
[e] Coast and Geodetic Survey gives 1,501.4 meters.

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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 619

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LOUISIANA AND TEXAS

BY

GEORGE CHARLTON MATSON

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By George Charlton Matson.

ACKNOWLEDGMENTS.

The cordial assistance rendered by citizens of northwest Louisiana and northeast Texas has added much to the value of this report, though so many persons have aided in the work that it is impossible to mention every one specifically. The Shreveport Chamber of Commerce, through its secretary, E. L. McColgin, took an active interest in the investigation and was especially helpful in suggesting sources of information and in obtaining the assistance of other organizations and persons. For information concerning logs of wells used in preparing the structural map special acknowledgments are due to those who are engaged in the production of oil and gas. Among those who have assisted in this work are C. D. Keen, manager of the Koster Oil Co.; W. B. Pyron, L. B. Webster, F. E. Chalk, and A. M. Arthur, of the Gulf Refining Co. of Louisiana; A. G. Curtis, manager of the Southwestern Gas & Electric Co.; C. K. Clark, C. C. Averill, and J. W. Anderson, of the Standard Oil Co. of Louisiana; Judge R. E. Brooks, president, C. N. Scott, vice president, C. K. Clayton, and C. R. Jones, of the Producers Oil Co.; O. A. Wright, manager of the Atlas Oil Co.; F. M. Hutchinson, president, and R. B. Nash, of the land department of the Higgins Fuel & Oil Co.; B. F. Rodgers, manager of the Rodgers Oil & Gas Co.; W. E. Morris, manager of the Cloverleaf Oil Co.; Carl Lemon, Vivian Oil Co.; S. A. McCune, superintendent of the Arkansas Natural Gas Co. at Vivian; D. C. Richardson, of the Richardson Oil & Gas Co.; Heilprin & Shropshire, W. C. Augurs, and William L. Henning.

LOCATION.

The Caddo oil and gas field is on the Gulf Coastal Plain in Caddo Parish, La., and extends from Louisiana a short distance westward into the eastern part of Marion County and the northeast corner of Harrison County, Tex. (See fig. 1.) The producing wells occupy an area extending northwestward from Mooringsport, La., for about 12

miles and a long, narrow belt extending nearly 10 miles northeastward from the north end of the main field. The belt which contains the most productive wells is not more than 12 miles in extreme length, and the large producing wells are scattered through a strip 4 to 5 miles wide, extending from Mooringsport to the north end of the field.

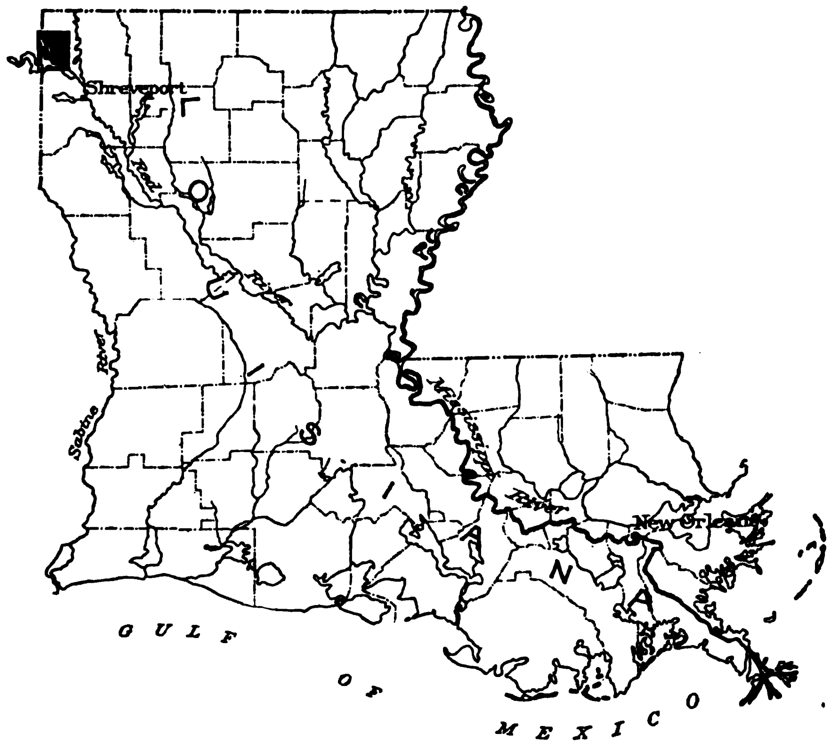

FIGURE 1.—Index map of Louisiana showing the location of the Caddo oil field.

The area has been divided into seven districts that merge more or less closely into each other. The Mooringsport district lies near the town of that name, and the Oil City district, likewise named for a town, adjoins the Mooringsport district on the north. West of the Oil City district is the Jeems Bayou district, and north of this is the Monterey district, which in this report is extended southward to include the Harts Ferry district. The Vivian district extends from the vicinity of the town from which it takes its name northeastward to Hosston, a somewhat detached area east of Oil City takes its name from Black Bayou, and an area northeast of Oil City is known as the Pine Island district.

The conditions in the area south of the Caddo oil and gas field favor the accumulation there of a large volume of gas and some oil. The areas that have been tested are limited to the city of Shreveport, where some good gas wells have been drilled, and the vicinity

of Naborton, Bayou Pierre, and Red River, where both gas and oil have been encountered and where small areas have been very productive. It is possible that other pools may be found between those already developed, but no favorable localities have yet been prospected. Close to these producing fields there is considerable undeveloped territory that might warrant exploitation.

HISTORY.

Natural gas has been known at Shreveport for more than a quarter of a century, though its exploitation at that locality was not begun until 1912, after large gas-producing areas had been developed in the northern part of Caddo Parish. Gas is now obtained from wells in a zone extending from Vivian and Hosston southward to and beyond Mooringsport. It is found as far west as Jeems Bayou and nearly as far east as Dixie, though the best producing territory lies between Black and Jeems bayous.

The Caddo gas field supplies natural gas to Shreveport, La., Marshall, Tex., and Texarkana, Little Rock, and several other cities in southwestern Arkansas. Since the supply, though large, is not inexhaustible, its proper utilization and conservation has become a matter of concern not only to the companies having money invested in wells and pipe lines but also to the citizens of the region supplied from the field.

The production of oil in 1906 was only 3,358 barrels, which is considerably less than was obtained in a single day by some of the large companies during the spring of 1913 and falls far below the maximum daily output of the new field in De Soto Parish. The production fluctuates greatly, being influenced chiefly by success in drilling, a single large well frequently more than doubling the output of a company. The field has produced a large amount of oil and there is reason to believe that there is still much remaining. The statistics given below have been compiled by the division of mineral resources in this Survey.

Petroleum production in the Caddo district, La.

	Barrels.		Barrels.
1906	3, 358	1911	6, 995, 828
1907	[1] 50, 000	1912	7, 177, 949
1908	499, 937	1913	9, 628, 177
1909	1, 028, 818	1914	7, 572, 254
1910	5, 090, 793		

In this field there have been several disastrous fires, resulting in nearly continuous loss of gas and periodic losses of oil. Burning gas wells have been especially numerous, because the early gas wells

[1] Estimated.

were imperfectly finished, and if once they caught fire it was extinguished with difficulty. One of the earliest burning gas wells, Producers No. 2, blew out in May, 1905, the gas escaping around the casing for a distance of several hundred feet and forming a mud volcano by loosening the earth. Another well that attracted considerable attention was just west of the Kansas City Southern Railway track. Probably the best known of the burning gas wells was the one in sec. 7, a short distance southeast of Oil City. This well burned for several years, and although it was frequently extinguished its presence caused enormous loss of gas and lowered the pressure of other wells in the Oil City district. Until recently the gas from this well escaped in the bottom of a pond of water, causing constant motion, the waves dashing several feet into the air. The ignited gas formed a striking spectacle, and the well was usually kept burning to evaporate the salt water from the pond and prevent its overflowing the adjacent land. The loss of gas was stopped in the summer of 1913, when the State conservation commission, with the assistance of the oil and gas companies, had the well killed by drilling a well near it to relieve the pressure and then pumping mud into the burning well until the flow of gas was stopped. An attempt will be made to avoid similar accidents by having the casings cemented at the bottom so as to prevent the escape of gas into the earth surrounding the wells.

The most noted of the burning oil wells was the Producers Oil & Gas Co.'s Harrell No. 7, in the SE. ¼ sec. 7, T. 21 N., R. 16 W. This well, which had a very large flow of oil, accidentally caught fire and was with great difficulty brought under control. This fire was probably the most spectacular one that has ever occurred in the field. The burning of the Star Oil Co.'s well No. 3, on the Louck's lease, was also a disastrous fire, and probably no greater ingenuity was ever shown in dealing with a burning well than was displayed in extinguishing the fire at this well, which was accomplished by drawing oil from the well, thus lessening the amount of fuel and making it comparatively easy to smother the flames with steam. The oil was drawn by running trucks carrying a pipe line into the flames and forcing the end of the pipe over the connections at the top of the casing. Oil then flowed through the pipe and was collected in an earthen tank situated beyond the reach of the flames.

PHYSIOGRAPHY.

CHARACTER OF SURFACE.

A large part of the Caddo oil and gas field is so level that it is very imperfectly drained. The largest tract of flat land is in the vicinity of Oil City, from which it extends westward to Jeems

Bayou and northward to Lewis. The level area is bordered by rolling hills, the remnants of an upland that formerly extended across the field. Some of the highest hills are southeast of Vivian, where small areas rise more than 300 feet above sea level, or more than 120 feet above low water in Caddo Lake. The transition from the lowlands to the hills is abrupt, some of the slopes being very steep. The most notable hill in the vicinity of the oil field is at the south end of Potters Point, where a bluff rises more than 130 feet above the level of ordinary low water in the lake.

ARRANGEMENT OF DRAINAGE.

The development of the present topography began when this region was a comparatively level upland covered by formations that have since been removed by erosion. Possibly remnants of the original upland may still exist on the tops of some of the highest hills that now surround the Caddo oil field, but in most places, if not in all, erosion has removed the materials that constituted the surface of this old plain. In shaping the present topography the streams followed the original slopes, so that the locations of the principal drainage lines were in a measure controlled by conditions that existed before the upland was greatly eroded. The major streams then eroded valleys where the rocks were least resistant, and some of the lines of least resistance coincided with axes of folds formed during an earlier geologic period. Thus the axis of the old valley from the Louisiana-Texas line nearly to Mooringsport agreed in position and direction very closely with the axis of the Caddo Lake anticline. This coincidence between structure and direction of the drainage accounts for the relation of the oil pools to the lake. The positions of the present tributaries of this stream may have been influenced somewhat by the structure of the underlying formations, though their relation to the structure is not so close as that of the stream which eroded the lake basin.

PLEISTOCENE TERRACE.

The period of erosion during the early Pleistocene and late Pliocene, when the principal valleys in Louisiana were formed, was followed during the Pleistocene by a period when drainage was obstructed by a relative rise of the level of the sea, which invaded the area now occupied by the prairies and some of the level pine lands in southern Louisiana and extended far up the rivers. This invasion of the sea checked the velocity of all the streams and caused the deposition of more or less sand and clay, which filled the valleys above their earlier levels. In places where the sea formed estuaries

the valleys were broadened by the action of the waves, which cut into the bluffs, and the material thus eroded away was deposited in the bottoms of the estuaries, producing a more or less even surface. This submergence may have extended into the region now occupied by the Caddo oil field, though if it did the water was probably only slightly brackish, because of the volume of fresh water brought in by Red River and its tributaries. The extensive plain that lies from 200 to 215 feet above sea level was developed during this period, and it is upon the surface of this plain that the numerous "gas mounds" are found. Subsequent drainage and erosion, together with other factors, have modified the details of the topography, but the general physiographic features have remained unchanged since the close of the period of submergence.

MOUNDS.

Low mounds occur on the level lands in the Caddo oil field and, though not evenly distributed, are numerous in the flat areas and present, though less common, on some of the more rolling land. They are from 1 to 5 or 6 feet high and 5 to 50 feet in diameter, and, though roughly circular, a few appear somewhat irregular because of partial overlapping of the edges of smaller mounds. These mounds are composed of light-yellow or gray loam or fine sandy loam, in places resembling the materials a few feet below the surface. They are separated by flat or basin-shaped depressions floored with clay, fine sand, or sandy loam. Similar mounds may be seen in places on the level lands near the coast in Louisiana and Texas and they extend northward into Arkansas, Oklahoma, and Missouri.

The common name of "gas mounds" conveys the idea, which is generally accepted, that these elevations were formed by gas escaping from below, but this explanation is probably incorrect, though it is possible that a few of them were formed in this way. Gas has produced similar mounds in the Caddo field by passing laterally through the subsurface sands and escaping through some weak point in the surface clays, bringing to the surface some of the sands that formed a subsurface stratum. It is possible that marsh gas arising from buried vegetation might similarly produce some low mounds, though the construction of the thousands of mounds that occur on the level areas would require more gas than could reasonably be expected from such a source.

Several other theories have been offered to account for these mounds. It has been supposed that they were made by men, by animals, by the wind, by water, and by pressure of the surface clays on subsurface sands. The wide distribution and the large number of these mounds

proves that they were not made by men. Somewhat more credible is the theory that they were made by animals, and of these, ants seem a more probable agent than burrowing animals. The peculiar distribution of the mounds in large numbers where the surface is level makes it improbable that they are wind-made, and their shape and size is an additional objection, because the wind usually builds large, irregular deposits in the most exposed situations, where conditions are most favorable for its activity. There is a further objection in the fact that the wind acts on a large scale only in regions of small rainfall and scanty vegetation, whereas the mounds are in a region where rainfall is abundant and vegetation luxuriant. There is, moreover, good reason to believe that uniform climatic conditions have prevailed since the formation of the plains that carry most of the mounds.

The theory that the mounds were formed by erosion does not appear tenable, because the effects of erosive action have been observed in many localities, and the only forms even remotely approaching those of the mounds are the low irregular ridges produced by floods. The pressure of surface clay on fine sands or sandy loam filled with water might cause the sands to be forced up through weak places in the clays to form mounds, though it is not probable that this process would operate on a scale large enough to produce such a great number of mounds. Probably in different places there have been several agencies at work to produce similar results, but it is not possible with the information available to determine the origin of all the mounds. Of all the agencies suggested the best explanation of the origin of a large number of mounds seems to be that they are the work of ants. The chief facts of economic importance are that most of the mounds were not produced by gas, and that even though they are found on level lands in gas and oil fields they are also found on similar areas where there is little or no gas or oil.

GEOLOGY.

STRATIGRAPHY AND LITHOLOGY.

GENERAL GEOLOGIC FEATURES.

If it were possible to examine the deposits in the Caddo oil field, layers of sands, clays, and limestones would be found arranged one above another in a manner similar to layers of masonry, only the layers or beds of the natural formations vary in thickness and in composition. Near the surface sands and clays predominate. In some places the sands are arranged in lenses or thin laminæ in the clay; in other places the clay occurs in lenses or thin laminæ scattered through

the sand. At greater depths well-defined sand beds are encountered and the clays occur in distinct layers; and at still greater depths there are thick beds of chalk separated by thin lenses of clay. Beneath these chalk beds lie other sands and clays and some limestones, and still lower there is another bed of sand and sandstones containing many lenses or partings of clay.

Geologists endeavor to separate into distinct formations those deposits that are either alike in lithologic character or that contain similar fossils. At some places several formations are assembled into a group or into a large unit called a series. The series here described and discussed are grouped under three systems, which are underlain by other older systems. The youngest system, known as the Quaternary, has been divided into two series, the Recent and the Pleistocene. Both are represented in the Caddo field, but the deposits are not of sufficient economic importance to warrant their subdivision in this report into formations. Beneath the Quaternary lies the Tertiary system, which has in other places been divided into four series, Pliocene, Miocene, Oligocene, and Eocene. Of these series only the oldest, the Eocene, is found in the Caddo field. The Eocene series of the Gulf region is generally subdivided into five formations, of which only three are found in the Caddo field, the Wilcox, Midway, and Claiborne. Beneath the Tertiary system lie the formations of the Cretaceous system, which is of unusual importance because it includes the formations that contain the oil and gas.

The Cretaceous of the western Gulf region has been separated into the Gulf or Upper Cretaceous series and the Comanche or Lower Cretaceous series, and these have been divided into formations, some of which have been assembled into groups, for example the Austin group, which represents a portion of the Upper Cretaceous series, and the Washita and Fredericksburg groups, which represent parts of the Lower Cretaceous series. The formations of the Gulf or Upper Cretaceous series are, in descending order, the Arkadelphia clay, the Nacatoch sand, the Marlbrook marl, the Annona chalk, the Brownstown marl, the Eagle Ford clay, including the Blossom sand member, and the Woodbine sand. In the Comanche or Lower Cretaceous series the following formations, named in descending order, have been recognized in southwestern Arkansas: Denison formation, Fort Worth limestone, Preston formation, Goodland limestone, and Trinity sand. The formations underlying the Trinity sand belong to the Paleozoic succession and have never been penetrated by any wells in northwestern Louisiana. They are too deeply buried to have any economic value, though some of them contain important oil and gas horizons in Oklahoma and Texas.

The following table shows the formations and their relationships in northwestern Louisiana. They are arranged in descending order, the youngest at the top and the oldest at the bottom.

Generalized section of formations in the Caddo field.[a]

System.	Series.	Group.	Formation.
Quaternary.	Recent.		
	Pleistocene.		
Tertiary.	Eocene.	Claiborne.	St. Maurice formation.
			Wilcox formation.
			Midway formation.
Cretaceous	Gulf (Upper Cretaceous).		Arkadelphia clay.
			Nacatoch sand.
			Marlbrook marl.
		Austin.	Annona chalk.
			Brownstown marl.
			Eagle Ford clay (including Blossom sand member at top).
			Woodbine sand.
	Comanche (Lower Cretaceous).	Washita.	Denison formation.
			Fort Worth limestone.
			Preston formation.
		Fredericksburg.	Goodland limestone.
			Trinity sand.

[a] The Upper Cretaceous formations do not outcrop in the Caddo field and are known from well logs only. The Lower Cretaceous rocks have not yet been reached in the wells of the district, but the formations enumerated in the table are probably present in the Caddo field.

Of the formations given in the table only those belonging to the Quaternary and Tertiary systems are exposed at the surface in the Caddo oil field. The Eocene beds are not fully exposed in the area covered by this report, and their discussion is based largely on observations in adjacent portions of Louisiana, Arkansas, and Texas, together with the knowledge obtained from well logs. The knowledge of the Cretaceous formations in northwest Louisiana is derived

only from well logs, and, so far as known, no borings have reached the base of the Upper Cretaceous. The data supplied by logs of wells are supplemented by material obtained from reports describing the Upper Cretaceous formations where they are exposed in northeastern Texas and southwestern Arkansas. Knowledge concerning the Lower Cretaceous is confined to the formations of that age to the north and northwest in Arkansas, Oklahoma, and Texas, where they are exposed at the surface. Their presence beneath the Caddo field may safely be inferred from the fact that they have a southeasterly dip in the area where they outcrop. Conclusions concerning the character and thickness of any of the Lower Cretaceous formations are less certain than those for the Upper Cretaceous, because they may not maintain the same lithologic characteristics and thickness at such a distance from their outcrops. However, the major subdivisions of the Lower Cretaceous should be recognized in deep wells, and the lowermost formation, the Trinity sand, should be present as a well-defined sand bed.

CRETACEOUS SYSTEM.

COMANCHE SERIES (LOWER CRETACEOUS).

Lower Cretaceous beds underlie the Caddo oil field, but they do not appear at the surface in the region. They are, however, of considerable geologic interest and they may prove to be of economic importance at some future time.

TRINITY SAND.

Though the lowest formation of the Lower Cretaceous, the Trinity sand, has not been penetrated in drilling, its presence and lithologic character beneath the Caddo field may be inferred from what is known of the geologic history of the region. This formation, according to Gordon,[1] consists of fine clean sand with occasional pebbles and bowlders of quartz derived by erosion and redeposition from the older Paleozoic formations. Lenses and laminæ of clay occur in the sand and remains of vegetable matter and brackish-water fossils are reported. In Caddo Parish the lenses of clay might naturally be thicker and more numerous than farther north, where the deposits were made nearer shore, though probably the base of the formation would be a comparatively pure sand and other porous sand lenses may be expected within the formation. Thin lenses of limestone may also be expected, since some occur in the formation in southwestern Arkansas.

[1] Gordon, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water-Supply Paper 276, p. 14, 1911.

GOODLAND LIMESTONE.

The Fredericksburg group of this region is represented by only one formation, the Goodland limestone, which in southwestern Arkansas consists of 25 feet or less of chalk or limestone. It may be a thicker and a purer limestone in the Caddo field, where the deposits were laid down in quiet water farther from shore. It was at first supposed that the bed of hard crystalline limestone encountered in some wells in northwestern Louisiana might be the Goodland or the Fort Worth limestone, but it is now known to be much younger.

WASHITA GROUP.

In northeastern Texas and Oklahoma the Washita group consists, in descending order, of the Denison formation, the Fort Worth limestone, and the Preston formation. In Louisiana these formations are all probably present but have not been differentiated because of lack of information about them; the group as a whole consists of clays and limestones with some sand beds. In Louisiana the upper portion can not be distinguished in well sections from the overlying Upper Cretaceous, unless the red clay that is so widely distributed represents the top of the Washita. The Fort Worth limestone, which is more than 50 feet thick in Oklahoma, might be recognized in wells.

GULF SERIES (UPPER CRETACEOUS).

The basal part of the Gulf or Upper Cretaceous series in the Caddo region is a succession of interbedded and interlaminated sands, clays, and shales that are not readily separable from the similar deposits forming the upper portion of the Lower Cretaceous. If the formations were exposed at the surface it would probably be comparatively easy to separate them, because the uppermost formation of the Lower Cretaceous contains more lime than the lowermost portion of the Upper Cretaceous. In examining well logs (see Pls. I–VI) it is rarely possible to determine the minor characteristics of the beds penetrated by the drill, and soft marls are apt to be classed as clay or gumbo, whereas hard marls are almost invariably called shale, unless they contain enough lime to be described as chalk. It is to be regretted that samples of drillings from some of the deeper wells are not available, as an examination of them might make it possible to determine where the Upper Cretaceous ends and the Lower Cretaceous begins.

WOODBINE SAND.

The lowest formation of the Upper Cretaceous in northeastern Texas is known as the Woodbine sand. This formation, according

to Gordon,[1] consists of ferruginous and argillaceous sands with some bituminous clays. The pyrite and glauconite (iron-bearing minerals) which it contains give the formation a yellow or brown color on weathering, and where the iron is concentrated it forms a cement that binds the sands together into a ferruginous sandstone. An abundance of plant remains aids in differentiating the Woodbine sand from the overlying marls of the Upper Cretaceous.

In the Caddo field the Woodbine sand is represented by a part, but not all, of the interbedded and interlaminated sands, clays, and shales that underlie the "sandrock" (1,800-foot sand, second gas sand) of the well drillers. It is not possible from well logs to determine the upper or lower limits of the formation, and it differs in character from the Woodbine sand of northeastern Texas by being more argillaceous, though it contains many thin beds of sand or sandstone.

EAGLE FORD CLAY.

Above the Woodbine sand are dark colored clays that contain some thin lenses of sand and earthy limestone, and above the clays is a sand or sandstone containing thin lenses of clay. This succession of beds is collectively known as the Eagle Ford clay, the sand and sandstone in the upper part being known as the Blossom sand member of the Eagle Ford clay.

Lower part of formation.—An examination of well logs in the Caddo field shows that the lower part of the Eagle Ford clay is composed of layers of varying character, described by drillers as shale and gumbo. Probably the variation depends on the hardness and plasticity, the harder layers being regarded as shale, whereas the soft plastic clays are called gumbo. The shale predominates and occurs in thick beds, separated by thinner layers of gumbo. Scattered throughout the beds are lenses of sand or soft sandstone, ranging from a few inches to more than 20 feet, but in few places exceeding 5 feet in thickness. The logs do not supply detailed descriptions of the lithology of the material, and it has not been possible to separate the Eagle Ford clay from the underlying Woodbine sand, though, as one is called a clay and the other a sand, they might reasonably be expected to be very unlike.

Blossom sand member.—At the top of the Eagle Ford clay there is a well-defined series of arenaceous beds which was called "sub-Clarksville" by Veatch[2] and Blossom sand member by Gordon.[3] In this report the name Blossom sand member will be used for the

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[1] Gordon, C. H., Geology and underground waters of northeastern Texas: U. S. Geol. Survey Water-Supply Paper 276, p. 16, 1911.

[2] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 25, 1906.

[3] Gordon, C. H., op. cit., pp. 19–21.

member described by Gordon, which consists of sand and rock known to oil operators as the second gas sand, the 1,800-foot sand, and the sandrock. The Blossom sand member is composed of sand or sandstone containing lenses of clay, the whole ranging in thickness from less than 50 feet in the southern end of the Caddo field to more than 100 feet in the northern end. The following sections show the character of this member in different portions of the oil field.

Section of Blossom sand member of Eagle Ford clay, from logs of wells.

Well in Marion County, Tex.

	Feet.
Packed sand	9
Hard sandrock	5
Packed sand	37
Hard sandrock	2

Well in the Oil City district.

Hard sand	20
Gumbo	6
Rock	3
Gumbo	13
Rock	5
Gumbo	5
Rock	4
Gumbo	9
Hard rock	5

Well in the extreme northern end of the Caddo field.

Sandrock	65
Gumbo	1
Sandrock	26
Shale and bowlders (probably interbedded sandrock and shale)	20

The gumbo of this section is probably shale. It will be noted that in addition to containing less clay the Blossom sand member is thicker here than in the preceding sections. Near the southern end of the field the proportion of sand decreases, and this member is thinner than in the section from the Oil City district, whereas in the northern part of the field the member is more sandy and thicker than in the first section.

A section of the Blossom sand member in the Mooringsport district shows 21 feet of sandrock that doubtless contained some shale partings.

Other wells show great variations from the sections given above, both in thickness and in the arrangement of the different materials, but there is a general similarity in their lithologic character. The term packed sand is used in these sections and elsewhere in the report to designate a loosely cemented, friable sandstone.

AUSTIN GROUP.

The Austin group of the Upper Cretaceous includes two formations, the Annona chalk and the Brownstown marl, both differing in lithologic character from the formations above and below.

Brownstown marl.—Above the Blossom sand member of the Eagle Ford is a series of marls and clays that contain a few lenses of impure limestone but are nearly free from sand. The transition from the Blossom sand to the Brownstown marl is generally abrupt, though in a few places, especially in the southern part of the Caddo field, there is enough interbedding of the sands and marls to make the separation of the two formations difficult. The change from the Brownstown marl to the overlying Annona chalk is gradual in many places, and well logs show limestone beds in the upper part of the marl, indicating a transition from one to the other.

The Brownstown marl, as described by Veatch,[1] consists of blue or gray clay containing more or less calcium carbonate. In the Caddo region the marls and clays vary in lithologic character, and the drillers' reports describe alternating beds of shale and gumbo containing a few thin lenses of sand and rarely one or more thin beds of chalk. The general range in thickness is 100 to 150 feet, the variation depending in part on the amount of material described as chalk. Extreme thicknesses of 50 to 300 feet have been noted, but in such logs the drillers did not make careful distinction between the chalk and marl.

Section in the Jeems Bayou district.

	Feet.
Annona chalk:	
Hard shale	31
Hard shale rock	11
Brownstown marl:	
Shale	79
Rock	3
Hard shale	5
Gumbo	28
Slate and shale	8
Shale	32
Eagle Ford clay (?):	
Hard shale (Blossom sand member?)	8

This section is unusually thick, probably because the first two members, with an aggregate thickness of 42 feet, belong to the overlying Annona chalk. The last 8 feet of the section may be a part of the underlying Blossom sand, for sandstone may easily be mistaken for shale if considerable clay is used in drilling.

[1] Veatch, A. C., Geology and underground waters of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 25, 1906.

Section of the Brownstown marl north of Caddo Lake.

	Feet.
Gumbo	50
Shale	16
Rock	4
Gumbo	8
Shale	62

The following section shows an unusual condition, where the chalk extends down nearly to the top of the Blossom sand:

Section of the Brownstown marl in the Caddo field.

	Feet.
Hard chalk rock with bowlders (Annona chalk?)	18
Sand	7
Shale and gumbo	17
Gumbo	20

The section below shows an unusual thickness of the Annona chalk, which accounts for the thinness of the Brownstown marl.

Section of the Brownstone marl north of Caddo.

	Feet.
Shale and gumbo	21
Gumbo	5
Hard sandy shale	30

The following section illustrates the thickness of the Brownstown marl in the northern end of the Caddo field:

Section of the Brownstown marl at north end of Caddo field.

	Feet.
Shale	90
Shale and gumbo	74

Annona chalk.—The upper formation of the Austin group, known as the Annona chalk, is one of the best known lithologic units of the Caddo oil field. It differs from place to place both in thickness and character, but there is at the top a series of interbedded blue or gray chalk with shale or gumbo. At greater depths the shale beds grow thinner, and near the base hard chalk predominates. This formation is not sharply separated from either the Brownstown marl below or the Marlbrook marl above. Apparently the conditions during the opening and closing stages of the deposition of the Annona chalk were such that chalk was being formed in some places while marl was laid down in areas near by. The transition from the Brownstown into the Annona was gradual, presenting some interbedding of the two, and the change from the Annona to the Marlbrook was still more gradual, with a general interbedding of marl and chalk.

Section of the Annona chalk, from log of a well northwest of Oil City.

	Feet.
Chalk rock	39
Chalk and shale	109
Oil sand	4
Chalk rock	7
Shale	8
Chalk rock	77

In a near-by well the Annona chalk has a thickness of 197 feet and is separated by 147 feet of shale and gumbo from a 13-foot bed of chalk above, which is probably the "Saratoga" chalk member of the Marlbrook marl, and many well logs give the total thickness of the chalk from the top of this bed. The logs of wells in the Caddo field show that the Annona chalk varies greatly in thickness, ranging from less than 200 feet to slightly more than 600 feet. As described by the well drillers the variation is in general between 300 and 500 feet, but the actual thickness of what has heretofore been classed as the Annona chalk in this region is less than the thickness given by the drillers, because in many of the recent logs of wells the measurement of the chalk is made from the top of the "Saratoga" to the bottom of the Annona chalk, thus including a portion of the Marlbrook marl.

Section from the log of a well in Marion County, Tex.

	Feet.
Marlbrook marl (?):	
Chalk ("Saratoga"?)	20
Gumbo and shale	148
Annona chalk:	
Chalk rock	121
Shale	105
Chalk	28

The 20-foot bed at the top of this section probably represents the "Saratoga" chalk, and if so the gumbo and shale below it belong to the Marlbrook marl.

MARLBROOK MARL.

The Marlbrook marl forms a very calcareous series of marls and clays that contains one layer of chalk known as the "Saratoga" chalk member, which appears to be very persistent. It also contains many minor layers of chalky marl or limestone that are sometimes classed by well drillers as bowlders and sometimes as limestone or chalk. This formation is well developed in the Caddo field and occupies the interval between the Annona chalk below and the Nacatoch sand above.

Though the thickness of the Marlbrook marl is irregular, the actual amount of difference is much less than appears from an examination of well logs, because many drillers describe as chalk all the beds

encountered below the top of the "Saratoga" chalk and the base of the Annona chalk. This gives the Annona chalk an apparent thickness greater than the actual and diminishes the apparent thickness of the Marlbrook marl. In other well logs it is thought that the soft layers in the upper part of the Annona chalk are described as shale, which gives an exaggerated thickness to the Marlbrook marl. Probably the correct thickness of the Marlbrook marl is from 325 to 375 feet, though extreme thicknesses, ranging from 175 to 450 feet, have been noted.

Sections of the Marlbrook marl, from logs of wells.

Well near Caddo.

	Feet.
Shale	8
Shale and bowlders	51
Hard shale	15
Gumbo	46
Shale	7
Gumbo	15
Shale	7
Gumbo	39
Chalk	20
Gumbo	87
Shale	22
Gumbo	26

Well in the Jeems Bayou district.

Shale	146
Gumbo	2
Gumbo and shales	32
No record	58
Gumbo and shale	28
Chalk rock	12½
No record	22½
Shale	50

Well in the Oil City district.

Marlbrook marl:	
Shale and gumbo	237
Chalk ("Saratoga" chalk member)	25
Shale and gumbo	135
Shale	9
Rock	1
Annona (?) chalk:	
Shale	185
Chalk rock	20
Shale	151

NACATOCH SAND.

In different parts of the Caddo oil field the Nacatoch sand has been known by local names, such as the "Caddo," the "Vivian," or the "Shreveport" gas sand. It is composed of light-gray to greenish fine

sand, alternating with layers of indurated sandstone and thin layers of clay. Locally the formation is calcareous, and in a few places the pores between the sand grains are filled with a cement of calcium carbonate, so that it contains little or no gas even where the structural conditions favor the accumulation of gas. The formation is in few places cemented, though it has been so reported in two wells out of the total number drilled—more than a thousand. Scattered grains of glauconite may be seen in some samples of the Nacatoch sand and their presence in samples from wells may be readily detected by the green color, except where it is obscured by a coating of petroleum on the surface of the particles of sand.

Where it is not filled with oil or gas the Nacatoch sand contains a large volume of salt water, indicating that the formation is very porous. The presence of shale and gumbo, which are reported in well logs, may be explained by the occurrence of clay lenses, though some of the material described as shale may be indurated fine sand.

In the well logs of the Caddo field the Nacatoch sand shows considerable variation in thickness, ranging from less than 100 to over 125 feet in some parts of the Mooringsport district to about 100 feet at Caddo, and to 175 to 200 feet in places near the northern end of the field. The wide variation is due in part to an actual thickening of the formation toward the north and west, and in part to the fact that in some places the Nacatoch includes beds of sand belonging to the upper part of the Marlbrook marl.

Section of the Nacatoch sand, from the log of a well near Mooringsport.

	Feet.
Gas rock	2
Sandrock	12
Gas rock	81

In the foregoing section the Nacatoch sand apparently has a thickness of 95 feet, which is below the average for the southern end of the field. Another log in the same district shows only 52 feet of Nacatoch, a thickness so slight that it is thought some of the Nacatoch may have been included in the Marlbrook marl.

The following sections show the thickness of the Nacatoch sand in different parts of the field:

Sections of the Nacatoch sand, from logs of wells.

Well in the Mooringsport district.

	Feet.
Sandrock with gas	20
Rock	2
Sandrock and shale	28
Hard rock	2

Well in the Jeems Bayou district.

	Feet.
Rock	4
Shale	3
Hard rock	5
Soft rock	8
Hard rock	1
Soft rock and shale	7
Hard rock	36
Sandy shale	50

Well in the Jeems Bayou district.

Rock	17
Hard shale	38
Gas rock	10
Hard shale	10
Gas rock	10

Well in Marion County, Tex.

Hard sand	10
Gas rock	9
Hard shale	8
Hard gas sand	16
Rock	3
Gas sand	28
Sandrock	3
Hard shale	47
Sand	23
Sandrock and sand	35

Well in the Monterey district.

Gas rock	10
Packed sand	33
Gas rock	1½
Packed sand	11½
Rock	2
Packed sand	28

In other wells in the Monterey district the Nacatoch sand ranges from 175 feet to slightly more than 200 feet thick, and the sections show sand and rock with very little shale.

ARKADELPHIA CLAY.

Above the Nacatoch sand is a tough dark-colored clay that in the well logs of the Caddo field is commonly described as gumbo and shale. Sands and sandstones are rare, though a thin layer of sandstone occurs in many places from 15 to 80 feet above the base. This sandstone bed is hard, like the upper layer of the Nacatoch, and the presence of gas just below it has given rise to the designation "false cap rock." Within a few feet of the base of the Arkadelphia clay in

many wells thin laminæ of sand are encountered. The basal Tertiary formation above the Arkadelphia clay is predominantly argillaceous, and therefore the line between the two formations can not be easily drawn in well records, though probably if the colors of the clays were given in the logs of wells it might be possible to separate the dark Arkadelphia clay from the lighter-colored clay above.

The maximum thickness of the Arkadelphia clay in the Caddo oil field may exceed 400 feet and the average thickness of the beds referred to that formation is from 300 feet to 350 feet. In determining the thickness it has been necessary to make more or less arbitrary distinctions that depend on incomplete information, and the measurements given should not be regarded as exact. In most well logs the materials assigned to the Arkadelphia clay contain more gumbo than shale, though in some wells the aggregate thickness of the shale equals or exceeds that of the gumbo.

TERTIARY SYSTEM.

EOCENE SERIES.

The Eocene is represented in the Caddo field by its two lowermost formations, which are in descending order the Wilcox ("Sabine") formation and the Midway formation. A small patch of fossiliferous clay belonging to the St. Maurice formation of the Claiborne group overlies the Wilcox formation southeast of Vivian, but in the Caddo field the area covered by this formation is not important. Doubtless other Eocene formations, together with some post-Eocene deposits, formerly extended over the region, but they have been removed by erosion and a portion of the Wilcox formation has also been carried away.

MIDWAY FORMATION.

The Midway formation is not easily separated from either the Wilcox formation above or the Arkadelphia clay below, though it contains fewer concretions (bowlders) than the Wilcox and less gumbo than the Arkadelphia. The formation is predominantly clayey, though glauconite and sand occur in thin layers. The well logs show thin beds of rock that are probably in part sandstone and in part limestone, though the descriptions are not sufficiently explicit to differentiate them. Probably the thickness of the Midway is from 200 to 300 feet, but accurate determination from well logs is not possible.

WILCOX ("SABINE") FORMATION.

The sands and clays that form the uplands of the Caddo field in this region belong to the Wilcox formation, formerly described as the "Sabine" formation by Veatch and other writers. Good exposures

of this formation may be seen in the banks of Ferry Lake and in many roadside gullies on the hills. Some sands and clays in cuts on the Kansas City Southern Railway are referred to the Wilcox and there are excellent exposures in the vicinity of Shreveport. Sands containing some glauconite may be seen in many places, and they alternate with lenses and beds of blue or gray clay. The sands contain many concretions, some of them several feet in diameter, and some thin layers of limestone, both of which are known to the well drillers as bowlders. Layers of lignite from a fraction of an inch to several feet thick are common, and locally the clays contain imprints of leaves or stems of plants. Some shells of marine organisms have been found near Shreveport, but these are not known to occur at more than one locality. The sands present great irregularity in the arrangement of the layers, being cross-bedded on a large scale, and the clay beds are commonly inclined at angles that differ from place to place. This characteristic has proved very confusing to geologists and has led to erroneous conclusions concerning the structure in many localities.

QUATERNARY SYSTEM.

Because of the thinness and the absence of structural features, the beds belonging to the Quaternary system are not important in the Caddo oil field. The sands and clays of this system rest on the eroded surfaces of the Tertiary deposits, and over a large area they conceal the older formations. Where they predominate they interfere with the study of the underlying formations, and in many places the only source of information concerning the structure of the region is the logs of wells.

PLEISTOCENE SERIES.

Some of the red sands and clays that form terraces above the high-water levels in the valleys are referred to the Pleistocene. They were derived in part from the underlying Tertiary formations, which they resemble in general lithologic character. The Pleistocene clays of the Red River valley are very plastic and contain considerable calcium carbonate, either finely divided or in nodules. The thickness of the Pleistocene is in most places less than 25 feet, though the maximum is considerably greater, in places slightly more than 100 feet.

RECENT SERIES.

The Recent series consists of the sands and clays deposited in the channels of the streams and the thin layers of silt spread by floods on the lowlands. These sands and clays resemble those of Pleistocene age and have the same general characteristics.

STRUCTURE.

GENERAL CAUSES AND FORMS.

The attitude of the strata, in so far as it departs from the normal position, is usually discussed under the head of structure. The original attitude of many sedimentary deposits is approximately horizontal, though in some places the strata are more or less inclined.

When sedimentary beds have been subjected to change of position which alters their attitude, structural features are produced that vary in character with the resistance of the beds and the intensity and direction of the forces causing the disturbance. The most common cause for such disturbances of the original attitude of deposits is pressure, and the strata may be either bent or broken. The bending produces folds and the breaking and slipping of severed edges of strata along planes produce faults. The accompanying diagram (fig. 2) shows simple types of folds, the upward bends being known as anticlines and the downward as synclines.

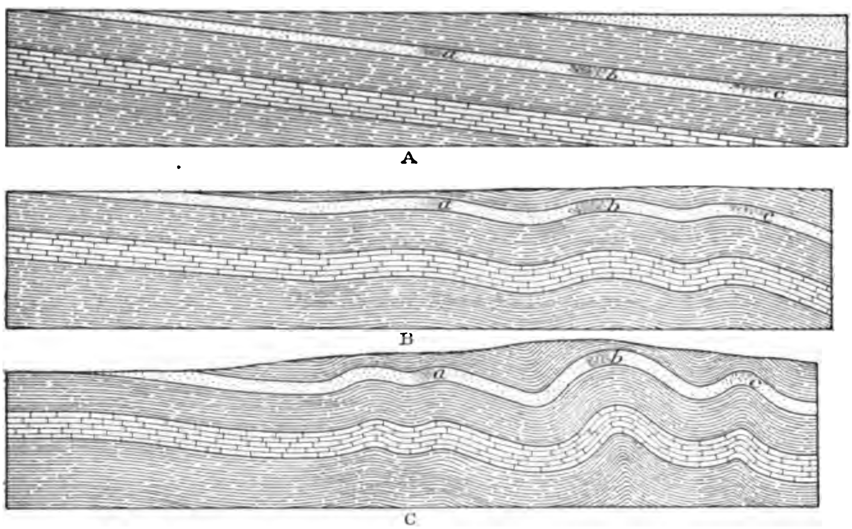

FIGURE 2.—Sections showing simple types of structure: A, Sedimentary beds with gentle dip; B, the same beds gently folded; C, the same beds more intensely folded.

Other types of folds and faults have been described, but they are not represented in the Caddo oil field, and the reader who desires information about them is referred to textbooks on geology or reports dealing with the subjects of folding and faulting.

METHODS OF REPRESENTATION.

Structure may be represented diagrammatically, as in Plate VIII, or by means of contour lines, as in Plate VII. These lines are drawn through points, on the top or bottom of a stratum of rock, that have

the same distance above or below a given horizontal plane, generally sea level. When contour lines are thus drawn at levels of every 25 or 50 feet of difference in elevation, or at any other definite interval (called contour interval) in elevation that may be adopted for the whole map, it is possible, by noting the closeness and the direction of the contours, to interpret the character, the direction, and the pitch of the slope at any point of the bed that has been uplifted or warped out of a horizontal position. The refinement with which the minor warping can be shown depends upon the amount and accuracy of the information and the refinement in contouring that can be based thereon. The elevation at any point of the stratum in the contoured area may be determined by referring to the elevations indicated by the nearest contour line. Diagrams give a more graphic picture of structure than contours, but their usefulness is limited because they show structure only along certain lines across the field. The use of contours possesses the advantage of showing the structure over the entire area shown on the map. In regions of complex folding and faulting, where it is impracticable to draw structural contours, diagrams may be necessary, but in regions where the rocks are only slightly deformed contour maps are more satisfactory. The reliability of the contouring depends on the adequacy of the information available. Usually some prominent bed of rock or some easily recognized formation is chosen as the base on which the contours are drawn.

In many oil fields of West Virginia, Illinois, and Pennsylvania persistent coal beds are used for this purpose, but in the Caddo field some one of the more persistent sands or a chalk bed is more useful. The formations thus chosen are known as key rocks. The contours show the key rock as it would appear if it were stripped of all overlying formations and had not been subjected to erosion.

ACCURACY OF THE STRUCTURE CONTOURS.

The position of the structure contours was determined by subtracting the elevations of the wells from the depth to the formation to be represented, thus obtaining the depth of the surface of the key rocks below sea level. The altitudes of the wells were obtained from the engineers of the various companies or from rapid leveling by the author. The elevations of a large number of wells were supplied by F. E. Chalk, engineer of the Gulf Refining Co. of Louisiana; J. W. Anderson, engineer of the Standard Oil Co. of Louisiana, gave a list of elevations for the wells of his company; and a partial list of elevations of the wells of the Busch-Everett and the Vivian oil companies was obtained from Carl Lemon. The author's instrumental work consisted of rapid leveling from the nearest points

of known elevation to the wells whose altitudes were to be obtained. Approximate elevations were considered satisfactory, and hence the determination was made to the nearest foot.

The logs of wells were supplied by the managers of different companies and by contracting drillers. In most of these logs, even the most accurate, some error exists, because measurements of depths to formations are made by computing the length of the pipe used in drilling. In checking these measurements by means of steel lines they are usually found to be 5 or 6 feet too great, and there is, in addition, an uncertainty in ascertaining the exact point where a formation is first encountered, though the amount of error resulting from this cause is not easily determined. A few logs appear to be so unreliable that they have been disregarded in drawing the structure maps. Fortunately, records of this kind are few, and the increasing tendency toward steel-line measurements should result in still greater accuracy. The use of reliable information obtained in that way will make possible the construction of more accurate structural maps and facilitate the systematic control of drilling operations.

In the present work it is believed that enough reliable information was obtained to permit the compilation of a structure map that is fairly accurate as to the general type of structure and the position and form of the major anticlines and synclines, although the details can not be shown until more data are gathered.

KEY ROCKS IN THE CADDO OIL FIELDS.

ANNONA CHALK.

The Annona chalk has been regarded as an important key rock because of its wide distribution and distinctive character. It possesses the advantage of being unlike the formations immediately above and below it, but unfortunately the drillers do not always separate it from the "Saratoga" chalk member of the Marlbrook marl, which is stratigraphically somewhat higher. Probably the true depth to the Annona chalk can be determined in these wells by adding the difference in depth between the two chalk beds where the depth to the top of the "Saratoga" chalk is given. The base of the chalk would be a valuable key for contouring if it were not for the fact that as long as the cuttings from the well appear white the material is classed by many drillers as chalk, even though the drill may have penetrated some distance into the underlying marl.

NACATOCH SAND.

One of the most useful formations for contouring is the Nacatoch or upper gas sand, as this formation is lithologically distinct from the strata above and below it, and it is reached in every successful

well in the field, whether shallow or deep. It is the first formation encountered that contains enough gas to be of economic value, and all successful wells are either drilled into it for the purpose of obtaining gas or through it to some of the deeper oil or gas horizons. Moreover, in most places the presence of the gas causes drillers to record the depth, even though they intend to drill to one of the underlying sands. Because of the large number of wells reaching the Nacatoch sand it has been possible to draw approximate contour lines for each variation of 25 feet in its elevation. (See Pl. VII.) These contours are placed on the same sheet with those showing the surface of the Blossom sand member of the Eagle Ford clay, which are represented by broken lines.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY.

The Blossom sand is present and readily recognized by most drillers, who designate it the 1,800-foot sand or the big sandrock, and its identification is facilitated by the presence of gas, which leads to its designation as the second gas sand. The Blossom sand is nearer to the deep oil-bearing formation than either the Nacatoch sand or the Annona chalk, and its structure more nearly corresponds to that of the oil sands, but it is not penetrated by as many wells as the higher formations, and hence information concerning it is not as complete. The broken contours on Plate VII show the variations in elevation of the surface of the Blossom sand for each 25 feet.

RELATIONS OF THE NACATOCH SAND AND THE BLOSSOM SAND MEMBER OF THE EAGLE FORD CLAY.

The relations of the key rocks, the Nacatoch and Blossom sands, have been examined to determine whether the interval between the two is constant throughout the oil field. Striking differences were found in some wells close together, amounting in places to more than 50 feet, which may indicate errors in recording logs, though a certain amount of variation is to be expected, because the upper surfaces of the two sands as originally deposited were probably somewhat uneven. The degree of accuracy in the determination of the depths to the sands differs from place to place and the decisions of different drillers as to the position of the tops of the sands do not always agree. After allowing for all these factors the persistent variations that remain suggest that the sands are not exactly parallel and that the change in the interval between them is not simply due to the thickening of the intervening formations toward some parts of the field and thinning in opposite directions. The discordance in dip of the two sands in places illustrates the lack of a constant interval between them and shows that the anticlines have slightly steeper slopes when the dip is measured on the Blossom sand than when it

is based on the Nacatoch sand. This condition suggests that the deformation began after the deposition of the Blossom but was renewed and culminated after the deposition of the Nacatoch. On the north slope of the Monterey uplift the contours indicate approximately the same dip for the two sands. The fact that the earlier folding in that region was slight may account for this condition, but it is more probably due to the generalized character of the map (Pl. VIII) in that area, where the information is scanty.

An examination of the contours shows that the axes of folds indicated by contours on the Blossom sand do not agree in position with the axes of folds shown by the contours of the Nacatoch sand. This disagreement was at first thought to be the result of inaccurate contouring but was subsequently found to be general, and the axes were found to bear a more or less systematic relation to each other. This peculiarity, together with the absence of systematic variation in the interval between the sands, suggests that some general explanation must be sought, either in the geologic history or in the character of the deformation. If the folding had been sufficiently intense the beds might have suffered unequal thrust and the Nacatoch sand might have been thrust bodily over the lower sand by crumpling of the beds or by shearing movement between the beds of the intervening formations. The extensive folding of this area, which culminated in the high anticline in the vicinity of Caddo Lake, brought about a complete reversal of the general inclination of the Cretaceous and Tertiary formations of the region. The original slope of the Cretaceous beds had been toward the southeast, but in the processes of uplift and deformation a general inclination toward the northwest was produced. This change was accompanied by a crumpling of the formations and a general shifting of the folds toward the northwest. The thrust was apparently tangential to the beds rather than parallel to them, so that the position of the folds in one formation was shifted more than in the other, though the readjustments caused by the unequal movement were doubtless in the form of crumpling rather than shearing, because of the plastic character of the intervening deposits. It is presumed that movements of this character may account for some of the variations in the positions of the axes of the folds shown by the contours of the surface of the key rocks.

SABINE UPLIFT.

The existence of interesting structural features in northwestern Louisiana was recognized by Veatch,[1] who says: "It [the Angelina-Caldwell flexure] has almost entirely destroyed the southern element

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 68, 1906.

of the dip of the beds between its northern border and a point about 60 miles south of the Paleozoic border." The Angelina-Caldwell flexure, as described by Veatch, extends from Angelina County, Tex., north of east, passing near Many, north of Nachitoches, and as far east as Mississippi River. The region affected by this flexure includes the territory from a short distance north of Nachitoches northwestward beyond the northern edge of the Caddo oil field.

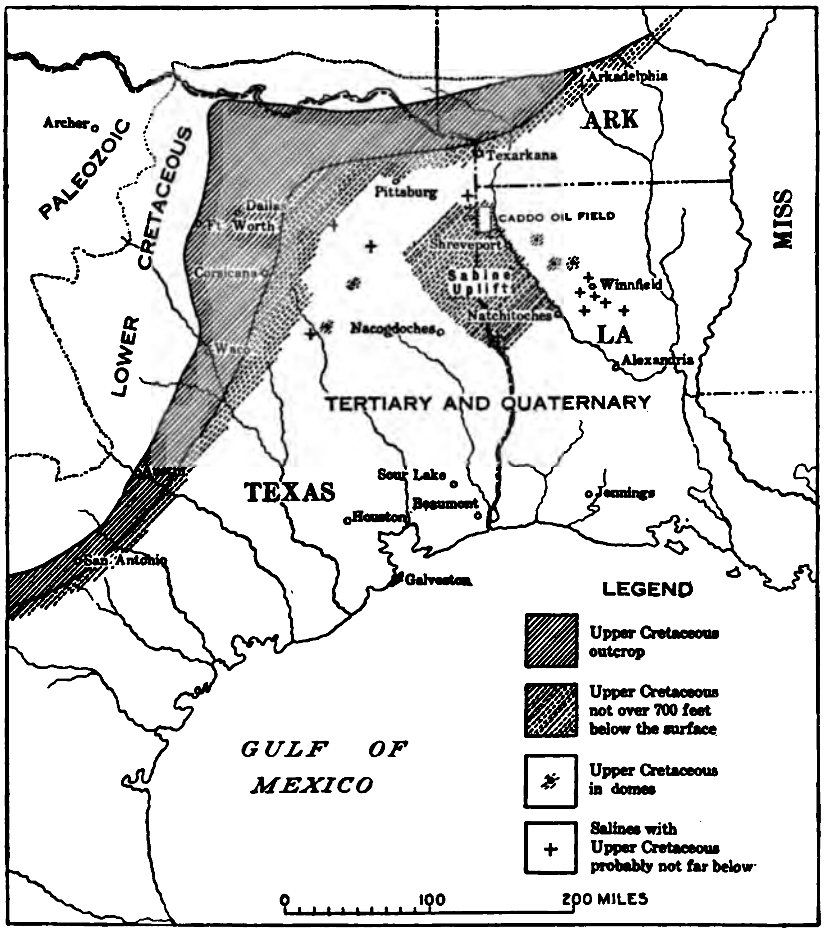

FIGURE 3.—Map of the Sabine uplift (after Harris) showing the important structural features in the Upper Cretaceous (gas and oil bearing) formations in eastern Texas and Louisiana. These formations dip beneath younger (Tertiary and Quaternary) deposits to the southeast.

The Sabine uplift (figs. 3 and 4), as outlined by Harris,[1] is given more definite form. The extensive crustal movements in its vicinity have brought Upper Cretaceous beds up within less than 700 feet of

[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, pp. 26–29, 1910.

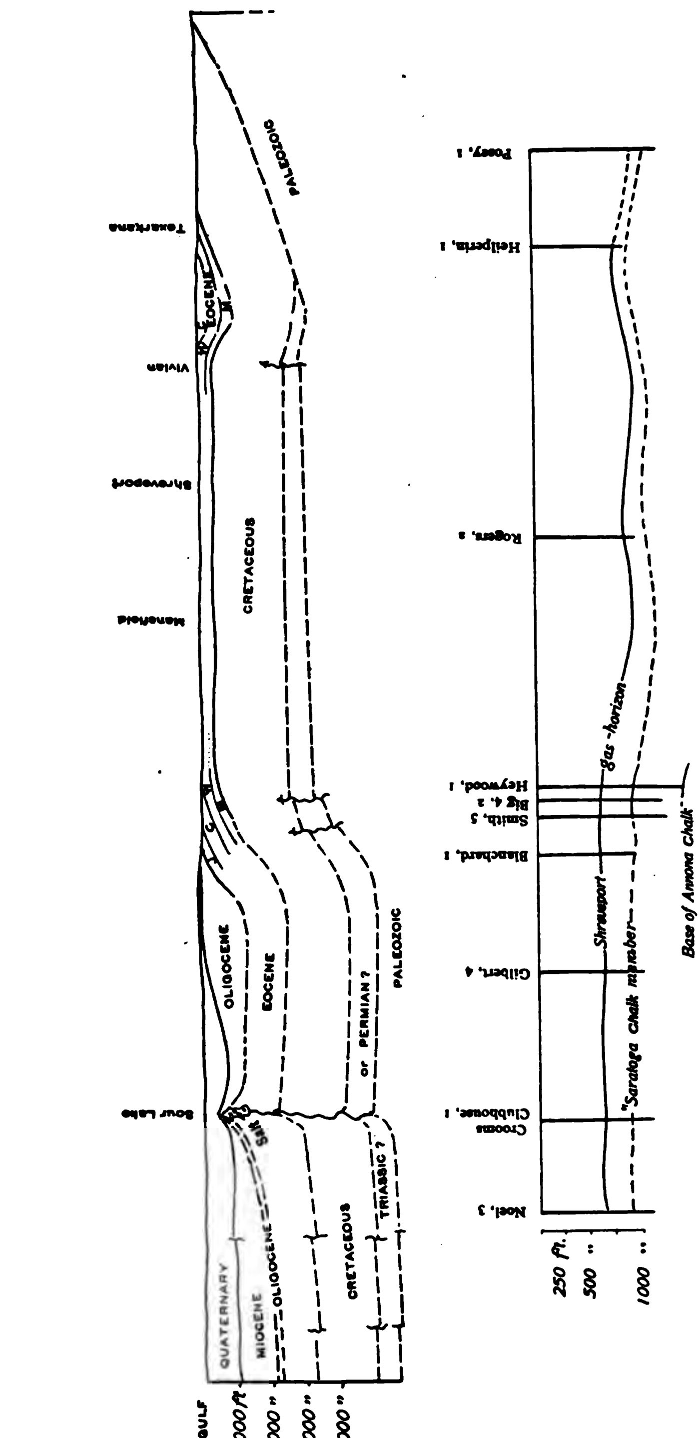

FIGURE 4.—Cross section of the Sabine uplift (after Harris) from the Paleozoic outcrop north of Texarkana, Ark., through the Caddo oil field and Sour Lake to the Gulf of Mexico, near Galveston.

the surface over a large area. This movement has brought about structural features of prime importance in oil and gas concentration.

This area is of great economic importance because it includes the Caddo, De Soto, and Red River oil fields, which, so far as known, are the only important Coastal Plain oil fields in Louisiana not located on the edges of salt domes. Probably future prospecting will develop other fields outside the Sabine uplift, but there is still much territory on the uplift that should be carefully investigated. In this bulletin a more detailed map of the Sabine uplift is not given because the discussion is limited to some of the important structural features on a portion of it, and an effort is made to show the relations of these features to the occurrence of oil and gas.

GENERAL STRUCTURE OF THE CADDO OIL FIELD.

The general structure of the Caddo oil field is anticlinal and synclinal, though the combination of different forces operating approximately at right angles to each other have produced complex folds of somewhat irregular shapes. Thus all of the folds have curving axes, some are apparently branching, and others lack definite anticlinal form, though this may be due to lack of information which could be used in representing the detailed structure. The successive folds rise in height from northwest to southeast, culminating just north of the eastern end of Caddo Lake, where the formations are structurally highest. South of Caddo Lake there are other folds parallel to those in the oil field, though they are somewhat lower and they may diminish in height toward the south for some distance beyond the lake.

The folds in the Caddo oil field are the result of pressure, and their general forms are typical of the structure in the territory underlain by thick deposits of Cretaceous and Tertiary age, though variations in details may be found in different places. Since they belong to types that are apt to be characteristic of the Gulf Coastal Plain region in western Louisiana and eastern Texas they deserve careful consideration.

The detailed structure of the Caddo field will be discussed on subsequent pages, but it may be noted here that the folds belong to two distinct periods. One series was produced by forces acting in a general northwest-southeast direction, producing anticlines and synclines with axes at right angles to the pressure. These folds are crossed by an axis, approximately at right angles to them and nearly parallel with the east side of the Sabine uplift. The pressure which produced this fold was at about right angles to that which produced the other folds. The two forces did not act simultaneously, for the southwest-northeast folds are clearly older than the folds at right

angles to them, as is shown by the fact that they are bent at the point where they cross the northwest-southeast axis.

Another effect of the last period of folding is the inclination of the crests of the older folds away from the points where the two series of folds intersect. This pitch, though less than the dip of the beds on the flanks of the anticlines, is noticeable on all the anticlines. Other folds parallel to the northwest-southeast axis are present, though the information available is not sufficient to show their outlines. They produce variations in the elevation of the crests of the southwest-northeast folds.

The best example of simple anticlinal structure is the fold east of Vivian, which is called the Vivian anticline in this report. Another relatively simple fold, which may be a southwestward prolongation of the Vivian anticline, passes through the northwest corner of T. 20 N., R. 16 W., and thence northeastward into the adjoining township. This fold, which is designated the Mason anticline, has, like the Vivian anticline, a distinctly curving axis. North of the Mason anticline is an irregular fold, called the Monterey uplift, which is a composite of several minor anticlines. The fold that extends from beneath the bed of Caddo Lake northeastward to the southern end of the Pine Island district has been named the Caddo Lake anticline. It is not known what form this fold may take in its extension to the northeast, but, judging from the available information, it has a definite branch toward the southeast just east of Mooringsport, and merges into a shorter fold nearly parallel to the Caddo Lake anticline. This short fold has been the source of some very large wells, but the producing areas are relatively small.

The Monterey uplift, which has been made to include the structural features north of the Mason anticline, is very irregular in shape, and it is difficult to show the details of the anticlinal and synclinal structures because of the small scale of the map. The forces that produced the small folds were here so nearly balanced that the resultant structures have rather indefinite outlines, though probably a part of the apparent lack of well-defined form is caused by the absence of information which would make possible the drawing of more accurate contours.

The syncline between the Caddo Lake and Mason anticlines is better defined than the others, though its bottom lies higher than some of the producing territory in the Monterey uplift. Another syncline is shown in secs. 21, 28, and 29, T. 21 N., R. 16 W. This trough is designated the Trees City syncline, though in reality it contains a number of minor anticlines. The portion shown on the map is high enough to be above the level of producing territory farther north. A broad area where the sands are relatively low occupies a tract

between the Vivian anticline and the Monterey uplift, but its form is almost as indefinite as the Monterey uplift, though here again lack of information may account for the inability to recognize a definite synclinal shape.

An examination of the structure where there is a large amount of information available reveals the fact that the folds of the Caddo oil field are not the simple forms that are represented on the maps and diagrams. It is apparent that each large fold is composed of a number of smaller ones having the same general shape and trend. These minor folds are too small to be shown on a map of the scale used, even if their outline could be determined, and at present the information concerning them is too meager to show their shape and distribution, except at a very few places. They play an important part in the oil development at some localities, because where other conditions are the same wells located on the minor anticlines are better than those in the minor synclines. Their influence is most noticeable on wells in the Nacatoch sand, and they are of least importance in the Woodbine sand, where other factors may have greater weight. The northwest-southeast axis of the Caddo oil field extends from the vicinity of Monterey to a point just east of Mooringsport. Its northern end pitches downward gently and bears the oil pool containing Harrell No. 7 of the Producers Oil Co., probably the largest well ever drilled in the field. The crest of this axis is uneven, as it is affected by the cross folds. It is high at the points where the northeast-southwest anticlines cross and low at the intersections of the corresponding synclines. The southern end, which is the highest, contains some excellent gas wells, and the northern end has produced a large amount of oil.

LOCAL STRUCTURAL FEATURES.

NACATOCH SAND.

VIVIAN ANTICLINE.

In the Caddo oil field three well-defined northeast-southwest anticlines, whose crests rise progressively higher from north to south, have been recognized. The Vivian anticline is a pronounced oval fold lying east of Vivian (Pl. VII). It has furnished a large amount of gas and has been an important source of oil from the Nacatoch sand. It possesses the general characteristics of all the folds, being flat-topped and having relatively steep dips on its northern margin. The southern limb of this anticline has not been extensively prospected, and it is not known whether oil will be found upon it. From theoretical considerations, as well as the meager informa-

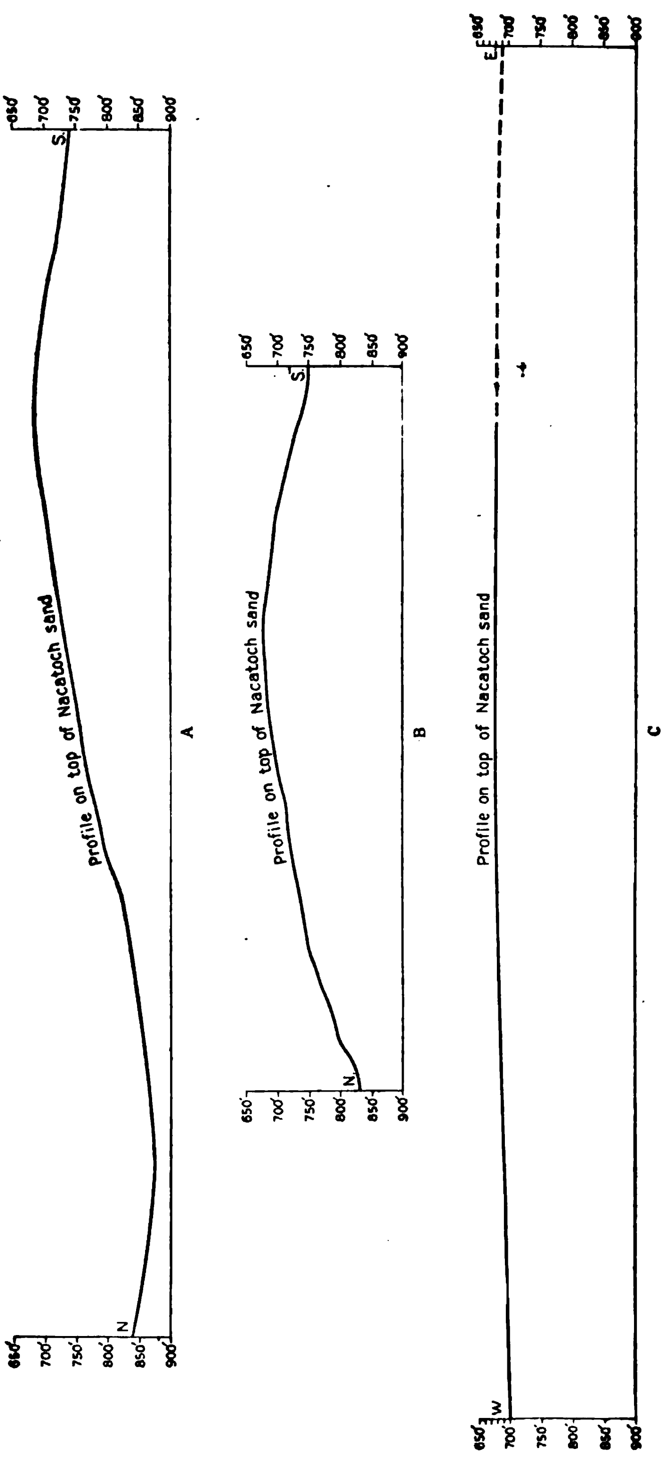

FIGURE 5.—Profiles of the top of the Nacatoch sand on the Vivian anticline: A, From locality near the southwest corner of sec. 34 to well in W. ½ sec. 18, T. 22 N., R. 15 W.; B, the highest part of the anticline in secs. 22, 27, and 34, T. 22 N., R. 15 W.; C, the crest of the anticline.

tion available, the southerly dips should be somewhat gentler than those toward the north, and this is confirmed by a few scattered well logs, together with information gained on a brief reconnaissance of the area.

The Vivian anticline has a curved axis, which results from a combination of the forces that produced the two lines of major folding. At the west end it curves southward and is partly interrupted by a broad syncline east of the Monterey pool. The eastern end of the anticline is bent southward, either as the result of the formation of another broad syncline or because of the downward flexing of the beds at the east edge of the Sabine uplift.

In profile C (fig. 5) the eastern extension of the apex is shown as a dotted line and is represented with a gentle pitch, a condition suggested by the flattening of the slope toward the northeast. The dry hole in the northwest corner of sec. 36 suggests that in some places the eastern end of the anticline may not be productive, but the evidence is not conclusive because the ground has not yet been thoroughly tested.

The occurrence of oil in the Nacatoch sand along the north slope of this anticline has led to extensive drilling and a large production of fuel oil was formerly obtained. Near the eastern end of the fold the line between the gas and oil was approximately along the contour where the sand is 780 feet below sea level. Below this line oil predominated, whereas above it gas was found. Salt water was encountered below the 800-foot contour, though a few small oil wells were drilled where the sand was slightly deeper. Because of the existence of local areas where the sands were elevated by minor anticlines successful wells were encountered in a few places at depths of less than 800 feet below sea level in the area below the 800-foot contour. Similar local irregularities account for the occurrence of gas at what appears to be unusually low levels, and minor depressions in the form of small synclines account for the existence of oil wells within the margin of the gas-producing territory.

Near the western end of the Vivian anticline the general northerly dip becomes gentler, and both gas and oil are found at greater depths in the Nacatoch sand. The influence of minor folds is also manifest over a much wider area; gas wells are found on minor anticlines among the oil wells, and oil wells are located in small synclines some distance southeastward in gas-producing territory. In some of these places, where the detailed logs of wells in the vicinity are available,

the local character of the folds is evident. For similar reasons the border between the oil and salt water is irregular, and the number of wells that are failures is apt to be large, because the success of a well on a small anticline, beyond the limits of supposed productive territory, encourages useless drilling. When the local character of the uplifts that give successful wells outside the main belt of production is understood it should serve as a check on extensive operations in unfavorable territory.

At the extreme western end of the syncline southwest of Vivian the oil extends to a somewhat greater depth than it does farther east, and many productive wells are obtained where the sand is more than 800 feet below sea level. However, the structure is connected with that farther west, and it will be discussed with the other anticlines.

MONTEREY UPLIFT.

The structure contours of the Nacatoch sand show complex folding south of Monterey (Pl. VII), with a long, gentle northwesterly dip and a similar but steeper inclination toward the west. The form of the uplift here is so lacking in symmetry that the term anticline is scarcely appropriate. The Nacatoch sand lies so deep on the outer margins of this uplift that large areas are barren, though oil has been found in the south half of sec. 10, T. 21 N., R. 16 W., and there have been a few shallow oil wells to the north and northeast, most of them beyond the 825-foot contour. A notable example of such a well is the Producers Oil Co.'s No. 1, Fee, in the SW. ¼ SE. ¼ sec. 3, T. 21 N., R. 16 W. This well is located near the 850-foot contour, but it encountered a minor anticline, where the sand was locally relatively high and a small production was obtained. To the north and west of this well and on the west side of Jeems Bayou the Nacatoch sand is low and is relatively barren. Near the southeast corner of the NE. ¼ sec. 21, T. 21 N., R. 16 W., a small supply of gas was obtained from one well. The formation has not been prospected for oil on the west side of Jeems Bayou, but to judge from the altitude of the sand only a small area near the bayou would be productive.

East of the bayou extensive areas of both oil and gas are known, and doubtless oil and, in some places, gas could be obtained from the Nacatoch sand in the bayou. In secs. 11, 12, 13, 14, 23, 24, 25, and part of 26, as well as farther south and east, oil and gas have been obtained from this formation. In this area, where the dips are slight, salt water is locally troublesome unless wells are carefully finished. Among the productive gas and oil wells in this territory are those which belong to the Rodgers Oil & Gas Co., and the large proportion of good wells indicates a general prevalence of favorable conditions.

MASON ANTICLINE AND SYNCLINE.

Oil has been found in the Nacatoch sand in Jeems Bayou and east of the bayou in sec. 34, T. 21 N., R. 16 W. The structure here (Pl. VII) indicates a slight easterly dip away from a small fold, the Mason anticline, that extends east of Masons Landing and northeast into sec. 34. The axis of this fold is curved sharply to the east in secs. 33 and 34. The principal wells obtaining oil from the Nacatoch sand belong to the Higgins Fuel & Oil Co. A gas well of the Koster Oil Co., in the SW. ¼ SW. ¼ sec. 34, is located on a minor anticline.

There is a broad syncline in the northern part of T. 20 N., R. 16 W., and the southeast corner of T. 21 N., R. 16 W. The Nacatoch sand in this syncline is mostly above the 800-foot contour, and oil may be obtained in the lowest portion. Gas is encountered in a minor anticline in the bottom of the large syncline and in the territory to the southeast, where the Nacatoch is relatively high.

CADDO LAKE UPLIFT.

On the Caddo Lake uplift (Pl. VII), the highest and most extensive in the field, the Nacatoch sand rises to less than 550 feet below sea level, and the distribution of the contours shows that the fold has a flat top and steep slopes. Throughout this large area the structure is favorable for the occurrence of gas in the Nacatoch sand. However, the formation thins greatly on some portions of this uplift, and locally its porosity is diminished, so that in some places it does not contain much gas. Development of gas has been extended along what appears to be a spur of this uplift southeastward nearly to the township line in secs. 31 and 32, T. 20 N., R. 15 W. Conditions favorable to the occurrence of gas continue to the northeastward through the Pine Island district and as far east as sec. 10, T. 20 N., R. 15 E.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY AND WOODBINE SAND.

MONTEREY UPLIFT.

The Monterey uplift (Pl. VII) is irregular in outline with slopes toward the west, northwest, and southwest that are extensive but not everywhere alike. The northwestward dip, as shown by contours on the top of the Blossom sand, is moderate, the maximum being 100 feet to the mile near the apex of the uplift and gradually decreasing to less than 50 feet toward the margin. The western slope is somewhat steeper, but there is a marked flattening of the dip on the outskirts of the uplift. Throughout the uplift the dips of the surface of the Blossom sand are slightly greater than those shown by the contours of the surface of the Nacatoch sand.

The interval between the top of the Blossom sand and the arenaceous beds in the Woodbine sand is somewhat irregular on the Monterey uplift, but the variations are in general less numerous than in other parts of the field. In a large number of wells the depth of the oil sand below the top of the Blossom sand lies between 350 and 375 feet; in many others the depths are from 330 to 350 feet. The interval between these sands as a rule is less than 330 feet, though in a few wells it falls below 300 and in two wells amounts to slightly more than 400 feet. In one well the interval between the tops of the sands is about 215 feet, and near the northern end of the uplift a well was drilled to a depth of 525 feet below the top of the Blossom sand before encountering a sand bed in the Woodbine, but these conditions are both unusual.

The Monterey uplift has been very productive. Successful wells were numerous, some of them very large, the best being the Producers Oil Co.'s Harrell No. 7, in sec. 4, T. 21 N., R. 16 W. The most uniform development has been on the leases of the Standard Oil Co., where the sands dip down toward the shallow Trees City syncline shown on the structural map. This territory has furnished a large number of excellent wells, and some of them have had initial productions of several thousand barrels a day. The bottom of the syncline is sufficiently high to be above the level where the beds are saturated with salt water and it has been uniformly productive. Deep drilling on the eastern slope of the Monterey uplift has so far proved unprofitable except near the southern end.

MASON ANTICLINE.

The crest of the Mason anticline (Pl. VII), as shown by the contours on the Blossom sand, extends from the vicinity of the Bonham lease of the Gulf Refining Co. northeastward to secs. 34 and 35, T. 21 N., R. 16 W., where it turns northward toward sec. 23 of the same township and range. The information on which this contouring is based is meager, and subsequent developments may necessitate considerable modification, especially near the northern end of this anticline. On the apex of the fold the Blossom sand rises to somewhat less than 1,675 feet below sea level, and the anticline has a flat top with steep dips toward the west and northwest. The production is mostly from one or more sands in the Woodbine at depths of 350 to slightly more than 400 feet below the top of the Blossom sand, which is shown by the broken contour lines on Plate VII. Some wells encountered sand beds that may have furnished oil at depths of about 250 to 260 feet and one at only about 215 feet below the top of the Blossom sand, but in a few the interval is greater than 400 feet. In

general drilling on the slopes and top of this anticline has been successful, and a large area has not yet been exploited.

The wells on the western side of this anticline have been uniformly successful, and some especially large ones have been procured by the Producers Oil Co., the Busch-Everett Oil Co., and the Standard Oil Co., in sec. 33, T. 21 N., R. 16 W., near the top of the slope, where the beds dip steeply down from the top of the fold. Farther southwest and across the State line in Texas the rich Burr pool of the J. M. Guffey Petroleum Co. is located farther down the slope of the anticline. The Standard Oil Co. has drilled a large number of successful wells on the north limb of this anticline as well as in the shallow syncline just north of it.

In the syncline south of the Mason anticline many successful wells have been drilled, some of them being large. The best yield in this portion of the field was from the Producers Oil Co.'s well on the Atlanta Shreveport Oil & Gas Co. lease in sec. 3, T. 20 N., R. 16 W. This well lies north of the bottom of the trough, and though the structure here is synclinal it should be noticed that the elevation of the Blossom sand is but little below the elevation of the same sand where the large wells were procured in sec. 33 in the township to the north, and it is not very different from the elevation of the Burr pool on the opposite slope of the Mason anticline. The interval between the top of the Blossom sand and the producing beds in the Woodbine sand is in most places about 325 to 375 feet, though a few wells contain sands within 250 feet of the top of the Blossom sand, and in still fewer there is an interval of slightly more than 400 feet.

CADDO LAKE UPLIFT.

Beneath the bed of Caddo Lake (Pl. VII) and extending to the east and southeast is a large anticline that represents the culmination of the structural features of the field, on which the Blossom sand rises to about 1,500 feet or less below sea level. The anticline is broad and its axis trends north of east, a branch apparently extending toward the southeast at a right angle to the main fold. North of Mooringsport this branch merges with an anticline that is approximately parallel with the Caddo Lake anticline. The axis of the anticline that extends into the Caddo Lake basin has a distinct slope (pitch) in a direction about west-southwest. The slope of the contours of the Mason anticline indicates a similar pitch, but the information concerning this territory is not as complete as that for the Caddo Lake anticline.

Many successful wells have been drilled on the north side of the Caddo Lake anticline, and those on the upper part of the slope, near the lake, have been especially good. In the vicinity of Caddo

some large wells have been obtained in the Annona chalk, but the wells penetrating the Woodbine sand in the same neighborhood have not been as successful as the structure would lead one to expect. In the Pine Island district good wells have been procured on the north slope of this anticline, but they have not proved lasting and much trouble has been experienced with salt water.

On the north slope of the Caddo Lake anticline the general range of depth for the Woodbine sand below the top of the Blossom sand is from about 325 feet to about 375 feet. Very few wells report this interval to be less than 325 feet, though in two or three it drops to 250 to 300 feet. Several wells encounter sands at 400 to 450 feet below the same datum plane; some wells penetrated as many as three successive sand beds and two sands are not uncommon.

On the top of this anticline wells have been generally successful, though many of them are small. Where there is a definite westward pitch to the crest of the fold some good wells have been obtained, and in sec. 19, T. 20 N., R. 16 W., where there is another anticline, a very rich pool contains a number of large wells within a radius of less than one-fourth of a mile.

Two other small pools, each with a single large well, were encountered on the anticline that lies south of the main Caddo Lake uplift and west of the extension to the southeast. One of these pools was located at the north edge of the village of Mooringsport and included the large Noel well of the Atlas Oil Co.; the second was near the boundary between secs. 26 and 35, T. 20 N., R. 16 W., and centered about the Star Oil Co.'s Loucks No. 3.

Meager information concerning the Woodbine sand on the apex of the Caddo Lake uplift indicates that although in a few places it is about 300 feet below the Blossom sand in most wells the intervals are from 350 to 375 feet. Some wells encountered the deep sand 400 to 450 feet below the datum and extreme depths of slightly more than 550 feet were reported. On the south and west sides of the uplift the development has been recent and information is not yet available for publication; however, the successful wells appear to be located on pools of smaller area than those farther north. Some oil has been obtained on the Standard Oil Co.'s Hunter lease in the northeast corner of the NW. ¼ sec. 5, T. 19 N., R. 16 W., on the Hardy lease belonging to the same company, on the south side of the lake, and on the lease of the Providence Oil & Gas Co. in Texas. A successful well has also been drilled by the Atlas Oil Co. in the south half of fractional sec. 17, T. 20 N., R. 16 W., thus extending the area of possible production somewhat beyond its former limits.

An unusually good well of the Brown Oil Co. is located in sec. 4, T. 20 N., R. 15 W.; it has been flowing steadily with a good yield for over five years. In sec. 10, T. 20 N., R. 16 W., the Black Bayou

and Natalie oil companies have drilled several successful wells, leaving a large intervening area untested. These wells are all located on the Caddo Lake uplift, but the information at hand is not sufficient to contour the structure in that portion of the field.

Some deep wells have been drilled near the eastern end, on the northern slope of the Vivian anticline, to test the Woodbine sand, but though good sand beds have been encountered they have proved unproductive. Another deep well was drilled toward the apex of the anticline on the south side. These wells all show some traces of oil in the Woodbine, but none of them encountered paying quantities.

STRUCTURAL FEATURES IN THE REGION ADJACENT TO THE CADDO OIL FIELD.

Structural features similar to those shown on the map of the Caddo oil field are known to exist at Shreveport and near Naborton in De Soto Parish. The structure at these localities is so much like that of the Caddo oil field as to suggest that it has a similar origin. If the northwest-southeast uplift of the Caddo field continues in a straight line it passes through the Naborton field but lies a short distance west of Shreveport. However, it is unlikely that any fold in this region has such great extent in a straight line, and it is more probable that the axis of the uplift curves slightly and is interrupted by numerous synclinal troughs.

SHREVEPORT ANTICLINE.

The Shreveport anticline is imperfectly known, but from the few wells that have been drilled there appears to be a low southwest-northeast fold comparable with some of those in the Caddo field. The Nacatoch sand has an elevation of less than 740 feet below sea level and in several wells it has been encountered at depths of 750 to 775 feet. This fold is high enough to permit drilling of successful gas wells, provided care is exercised in finishing them. Salt water is troublesome in some of the minor synclines that are superimposed on the major fold, and there is a great variation in the yield of gas wells situated a short distance from each other. In general those wells that encounter the sand on one of the minor anticlines similar to those described in the discussion of the Caddo field are more successful than the wells situated in the synclines. Toward the southwest edge of Caddo Parish, in the vicinity of Keithville, enough drilling has been done to show that the Nacatoch sand is too low to supply gas, though a small quantity occurs, together with much salt water. A somewhat similar difficulty was encountered at Reisor, a few miles north of Keithville.

The Shreveport anticline has not supplied any oil, though a few attempts have been made to test the deep sands. In general the formations below the Nacatoch appear to be somewhat more sandy

than they are farther north, in the Caddo field. This anticline should be thoroughly tested at least to depths as great or slightly greater than the pay sands in De Soto Parish.

FRIERSON.

Veatch[1] reports gas and salt water in the Nacatoch (?) sand at Frierson at a depth of 800 feet below sea level. More definite information from this locality suggests that the sand described may have been an unusually thick lens in the lower part of the Arkadelphia clay, and that the Nacatoch sand may lie 20 to 30 feet deeper. Here, as at Shreveport, all the Cretaceous formations are more sandy than in the Caddo field, but unless some locality can be found where the sands are higher than where deep drilling has been done there does not appear to be any favorable indication of the occurrence of either gas or oil in commercial quantities.

NABORTON AND VICINITY.

In De Soto Parish structures similar to those in the Caddo field have been known for some time, and though detailed information concerning this field is not available for publication, the anticline in the vicinity of Naborton is known to be about as high as the Caddo Lake anticline. All the Cretaceous formations contain a larger proportion of sand here than they do in the Caddo field, and the oil comes from a deeper bed, possibly in the Woodbine sand or some older formation. It is not yet known whether the Naborton pool is located on the highest part of this uplift, but the sands distinctly pitch south of west and the fold passes north of the properties owned by the Mansfield Gas Co. Dips both north and south from the pool indicate that the field is near the axis of the anticline, and if there are any higher portions they must lie northeast of the producing wells.

Other anticlines similar to the one at Naborton occur at intervals as far south as the northern line of Natchitoches Parish, but the height of the successive folds diminishes toward the southeast, and those nearest the Naborton anticline may be more favorable locations for wildcat wells than those farther south.

North of the Naborton anticline a similar fold probably accounts for the large gas well of the Producers Oil Co. Between this locality and Shreveport there probably are other folds of similar character, but that area has not yet been examined in detail.

SABINE PARISH.

About 15 miles south of the Naborton field, in De Soto Parish, drilling has been carried on for two or three years. Since the prepara-

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 26, 210, 211, 1906.

tion of the major portion of this report a small well yielding some oil has been finished in the southern part of T. 10 N., R. 12 W., a short distance south of the boundary between De Soto and Sabine parishes and only a few miles from the town of Pelican on the Texas & Pacific Railway. This successful well is of considerable interest because it expands the area of possible production nearly to the southern boundary of the Sabine uplift of Harris. The producing sand is reported at somewhat greater depth than in De Soto Parish.

In Tps. 7 and 8 N., R. 12 W., several wells have been drilled by McCann & Harper for the Lumberman's Oil & Gas Co., but none of them have been successful. The logs of all these wells are difficult to interpret in the absence of samples of the drillings or of fossils from the formations below the surface. However, it is possible that the Nacatoch sand has been reached in only one or two of these wells, where a sand is reported to contain a large volume of salt water. Opposed to this theory is the fact that chalk is reported in all the wells at depths which vary from 2,000 to 2,500 feet from the surface. However, this chalk may be a limestone in the basal Eocene (Midway formation). These interpretations are tentative and subject to revision whenever satisfactory samples can be obtained from deep drillings in this neighborhood. It is, however, certain that none of the wells have reached the deep producing sands of the Caddo or De Soto Parish fields. From Veatch's report[1] it appears that there should be a very distinct flexure (the Angelina flexure) crossing this part of Sabine Parish, and from comparison of some of the well logs it is inferred that this or a similar fold may lie south of the wells drilled for the Lumberman's Oil & Gas Co. This suggestion is, of course, tentative, because this field has not yet been examined to determine the exact structure, and it may be found on careful examination of the region that the Angelina fold passes to the north of this group of wells, in the neighborhood of the Logan well of the Pasadena Oil Co.

OCCURRENCE OF OIL AND GAS.

NACATOCH SAND ("CADDO" GAS SAND, "SHREVEPORT" GAS SAND).

The Nacatoch sand (see Pl. VIII) is the most important gas sand of the field and has produced some low-gravity oil suitable for fuel. The description of the formation given in the discussion of the geology includes some sections selected from among a large number of well logs. These sections show that the formation contains many alternations of soft and hard layers, locally known as cap rocks. The thickness of the formation ranges from about 50 feet to over 150 feet,

[1] Veatch, A. C., op. cit., pp. 26, 210, 211.

but only the upper part contains oil or gas. Locally, as at some points east of Vivian, the gas occurs in the upper part of the formation, separated from the oil or salt water below by a hard bed known as a cap rock, but even in wells located near each other this cap rock may lie between the oil and gas in one and not in another, because the hard layers are not persistent. Where the gas or oil bearing sand is limited to a few feet in the upper part of the formation it is necessary to use great care in completing a well, because if it is drilled too deep or the gas is allowed to flow unchecked salt water may interfere with production. In the early development of the field this was not always understood, but the danger of salt water is now avoided, as far as possible, by drilling only a short distance into the formation, or in many gas wells by merely puncturing the hard rock that caps the sand.

ANNONA CHALK.

The Annona chalk has supplied to a few wells large quantities of oil of relatively low gravity, which may occur in crevices or in porous beds of chalk or sand of small extent. The initial yields of some of these wells have been large; for example, the Richardson and Busch-Everett wells, east of Caddo, and the Alamo well No. 2 of the Caddo town site. The Alamo No. 2 was a large gusher and attracted the attention of many operators from the salt-dome fields of the Gulf coast, who acquired small holdings in the vicinity and drilled a large number of unsuccessful wells.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY.

The Blossom sand (1,800-foot sand, sandrock; see Pl. VIII) is discussed under the heading "Geology." Nearly all wells that penetrate this sand are reported to show strong gas pressure with salt water immediately below. During 1913 the Arkansas Natural Gas Co. finished a gas well in this sand which had a capacity of 18,000,000 cubic feet, and it is probable that other attempts will be made to develop this gas, especially in portions of the oil field where it is difficult to obtain enough gas for drilling and pumping operations. Some showings of low-gravity oil are reported in the Blossom sand, and one successful well is thought to derive oil from it, though in no other places have attempts been made to test the oil-bearing capacity of this sand. Wells located near the margin of the area where the formation contains gas should furnish favorable opportunities for determining the value of the oil showings.

WOODBINE SAND.

The Woodbine sand is the source of the high-grade oil in the Caddo field, and in many places there is sufficient gas to cause strong flows

when the wells are first drilled. Locally, where conditions are especially favorable, large yields of dry gas are encountered in this formation, though when allowed to flow freely some of the gas wells soon yield oil. The depth to the oil in the Woodbine sand differs from place to place and in many parts of the field two or more producing sands are reported in the same or in different wells. In general it may be said that there are two fairly definite productive horizons, one about 225 to 275 feet below the top of the Blossom sand and another about 325 to 375 feet below the same datum. The variations from these depths are numerous and the exact depth of the oil sand in many wells is not determinable, because the drillings show so little sand as to give the impression that the oil comes from one or more of the numerous shale beds. The small quantity of sand is due to the fact that the well is finished near the top of the sand. In many places wells of this kind yield a large quantity of oil for a short time. The approximate depth from the surface to the oil sand can be obtained at any point on the map by adding 225 to 375 feet to the elevation of the surface above sea level plus the depth of the Blossom sand below sea level. It is not known whether extreme depths of 500 to 550 feet below the top of the Blossom sand indicate local lenses of oil-bearing sand below the principal horizons or whether the figures given are erroneous.

A still deeper sand than those mentioned in the foregoing discussion is shown by the logs of some wells, but its capacity for producing oil has not been adequately tested. It was probably this sand that supplied some oil of surprisingly low gravity in the Standard Oil Co.'s Barlow No. 1. The low gravity may have been due to a loss of volatile constituents as a result of flowing through a large volume of warm salt water, and it is to be hoped that this horizon will be more thoroughly tested at localities where the structure is favorable with the salt water from the higher sands excluded.

The porous beds in the Woodbine sand are very irregular in distribution, and a few detailed sections have been selected to show their relations.

Detailed sections of parts of the Woodbine sand.

No. 1.

	Feet.
Rock	5
Shale and sand	2
Hard sand showing oil	21
Shale	11
Gumbo	14
Shale and oil sand	40

No. 1—Continued.

	Feet.
Shale	12
Gumbo	5
Sandrock showing some oil	17
Sandrock	14
Packed sand	6
Shale	2

Successful, nonflowing.

Detailed sections of parts of the Woodbine sand—Continued.

No. 2.

	Feet.
Gumbo and shale	24
Shale	11
Gumbo	16
Hard shale	24
Hard gumbo	22
Gumbo and shale with some sand	39
Hard sandy shale, in part red	27

Flowed by heads.

No. 3.

	Feet.
Shale and gumbo	42
Shale	20
Sandrock showing oil	4
Shale and sandrock	5
Shale and gumbo	40
Sandrock	1+

A good well.

No. 4.

	Feet.
Gumbo	15
Gumbo and shale	3
Black shale	6
Hard shale	19
Shale showing light oil and gas	10
Shale	5
Pink shale	10
Hard shale	4
Rock	1
Hard rock	2
Rock	3
Oil and gas sand	10
Shale	5
Rock showing oil	11
Hard rock showing oil and gas	4

No. 5.

	Feet.
Gumbo	10
Rock	1
Sandy shale showing oil	80
Hard gumbo	17
Hard shale	10
Oil sand showing a little oil	12
Limerock	13
Hard shale	10
Rock	4
Sandrock	9
Sand and shale showing oil and salt water	12
Gumbo	8
Rock	6
Hard shale	15
Gumbo	9

No. 5—Continued.

	Feet.
Shale with layers of rock	9
Gumbo	6
Hard shale	19
Rock	1
Brown shale	15
Rock	2
Brown shale	16
Rock	2
Sandy shale	18
White rock	3
Blue shale	10

A salt-water well.

No. 6.

Top of section 255 feet below top of Blossom sand.

	Feet.
Hard shale	11
Rock showing gas	5

Top of this sand 266 feet below top of Blossom sand.

	Feet.
Hard sand	14
Soft rock and shale	15
Hard black shale	12
Soft shale and rock	72
Hard gas rock	3

Top of this sand 383 feet below top of Blossom sand.

	Feet.
Hard slate and rock	14
Soft shale showing oil	15

Top of this sand 410 feet below top of Blossom sand.

	Feet.
Rock and hard shale	47
Soft shale	4
Hard shale and rock	4

No. 7.

Top of section 135 feet below top of Blossom sand.

	Feet.
Gumbo and shale	40
Hard thin laminated shale	23
Shale	56
Hard shale	43
Shale	92
Pink shale	6
Rock or hard shale	2
Pink shale	4
Gumbo	3
Soft rock or shale	2
Shale	65

Detailed sections of parts of the Woodbine sand—Continued.

No. 8.

Top of section 214 feet below top of Blossom sand.	Feet.
Shale and gumbo	69
Gumbo	15
Shale and packed sand	25
Shale	13
Shale and packed sand	62
Rock	3
Shale	20
Sand and pink shale	20
Oil sand, top of which is 441 feet below top of Blossom sand	10

No. 9.

	Feet.
Hard shale, top of section 283 feet below top of Blossom sand	72
Shale, top of which is 355 feet below top of Blossom sand, small showing of oil	17
Red shale	7
Gray and red shale, salt water 379 feet below top of Blossom sand	18

ACCUMULATION OF OIL AND GAS.

CONDITIONS OF ACCUMULATION.

When the occurrences of oil and gas were first investigated, it was found that their distribution was in many places closely related to the geologic structure. The anticlinal theory of oil and gas accumulation resulted from the attempt to explain this relation. This theory was presented to explain the occurrence and relations of oil, gas, and salt water as actually observed in oil pools, and according to it the gas, the lightest substance, is present in the upper part of the anticline; the next heavier substance, the oil, lies below the gas, and beneath the oil is salt water. According to the theory these substances were originally mixed together, and subsequently separated and arranged themselves in the order of their specific gravities.

Nothing was said as to the condition of the water, whether it was under hydrostatic conditions (stationary) or under hydraulic (moving). The important points in the anticlinal theory were that the gas, oil, and salt water were originally mixed together in a porous formation, and that their separation and arrangement in their present positions, with existing relations, was due to their relative weights. This relation is the one which exists where the conditions are ideal—that is, where all the factors governing accumulation are equally balanced.

More recently detailed studies of oil and gas fields have disclosed the fact that the ideal conditions described above are not invariably present, and experimental investigations[1] have thrown doubt on the power of gravity alone to cause the separation of the substances in such porous sands as are found in oil fields. It may be impossible to arrive at a safe conclusion, based on a few months' laboratory observations, concerning the action which might take place in deeply

[1] Munn, M. J., Reconnaissance of the Grandfield district, Okla.: U. S. Geol. Survey Bull. 547, pp. 78, 79, 1914.

buried sands during long geologic ages. However, the conclusion that the water has been under hydraulic conditions is sound and will hold for any extensive sheet of water occupying porous beds, for otherwise all water found in sands of marine origin would be salt. No doubt the folding of water-bearing beds may cause circulation of the water, but unless the folds are lifted above the saturated area where water enters the porous beds the effect of folding will be slight. Probably the chief movement of the water caused by deformation will be away from the folds because of the shortening of the beds as a result of the pressure that caused deformation. This shortening is accomplished by forcing the particles of the deposits close together, thus diminishing the size of the openings between them, and if the formations are saturated with water some of it must be forced out when the size of the openings is reduced.

Wherever there is an opportunity for water to escape from sands at some distance below the intake hydraulic conditions will prevail. This permits the forward movement of water from the place where it enters the ground to the place where it escapes from the sand. The motion of the water under such conditions is caused by gravity and capillarity, and its rate will be controlled by the general slope of the bed, its porosity, and the rate of escape of water from the bed farther down the dip. Variations in the rate of movement in different portions of the same bed will be caused by changes in the porosity and local variations in the altitude of the bed. Wherever there is lessened porosity, as where the sand becomes finer or is replaced by clay, moving water will be retarded and it may also be checked by folds. In such situations as this oil and gas are found, though no extensive accumulations of oil or gas against obstructions on a uniform dip away from the outcrop (see fig. 2, p. 28) have ever been recorded, which suggests that gravity is in reality an important factor in accumulation.

ACCUMULATION IN THE CADDO FIELD.

In the Caddo oil field the rocks appear to be everywhere saturated, so that no extensive dry sands are encountered, and the oil and gas pools occur in intimate relation to structure with barriers, such as relatively dense impervious layers or lenses of fine sand or clay, forming an important element in the Woodbine sand. The oil and gas are thought by the writer to have reached their present positions under the influence of gravity and capillarity, which produced motion of the oil, gas, and salt water and influenced their segregation. The rate of movement was doubtless slow, though probably at some periods it was much more rapid than at others.

NACATOCH SAND.

The conditions in the Nacatoch sand approach the ideal in spite of the numerous dense layers in that formation. In consequence exploitation has shown definite relations between anticlines and the distribution of oil, gas, and salt water, though the volume of gas and oil causes the oil to extend down to the bottoms of some of the shallow synclines. The only exceptions to uniformity of distribution of these substances are due to the existence of minor anticlines and synclines superimposed on the major folds. Nowhere in the field has the exploitation been carried completely around any of the major folds, but the north and west sides have been productive wherever prospected. Some territory that may yield oil still remains on the west and northwest sides of the folds. It is problematic whether the east and south sides of the folds will supply oil from this formation, except east of the Monterey uplift and the Mason anticline. The general dip of the beds and consequently the direction of circulation of water is southeastward from the outcrop of the formation in northeastern Texas and southwestern Arkansas. This would afford the most favorable conditions for accumulation of oil on the north and west sides of the anticlines but not necessarily on the opposite sides. However, the success of wells east of the Mason anticline and the Monterey uplift should encourage drilling south of the Vivian anticline, especially near the western end. Somewhat less promising conditions may be expected south of the Caddo Lake anticline, and the territory south of the western end of this fold may afford better opportunities than that farther east. The least promising territory for oil in the Nacatoch sand is south of the east end of the Caddo Lake uplift.

The exploitation of the gas in the Nacatoch sand has been distributed generally over the uplift, though probably more intensive development operations will yield returns within the oil-producing territory on minor anticlines where the sand is relatively high. The Mason anticline is highest in the NW. ¼ sec. 4 and the SE. ¼ SW. ¼ sec. 33, where the surface of the sand is reported to be less than 730 feet below sea level. The apex of this fold appears to be more favorable for the accumulation of gas than elsewhere on the west side of Jeems Bayou, and if the information concerning the sand in that locality is correct it would warrant drilling for gas in the Nacatoch.

ANNONA CHALK.

The source of the oil in the Annona chalk is problematic, but the most credible explanation of its presence is that it has risen from below along fissures and either accumulated in porous beds or in

crevices in the chalk. The large wells as a rule contain considerable gas and flow vigorously for a few weeks, but the yield soon declines. Opposed to this theoretic explanation of the source of the oil is the fact that its specific gravity is lower than that of the oil found in the underlying formations. However, this condition may possibly be explained by the relief in pressure as the oil passes upward to the chalk, which permits the separation of the lighter constituents to form gas. The general parallelism of structure lines with the distribution of the chalk wells near Caddo suggests that in that place there may be fissures which afford opportunities for the oil to migrate from the older beds into the Annona chalk. The erratic occurrence of oil in the Annona chalk, together with the short life of the wells, has discouraged attempts at exploitation, for the few successful wells do not counterbalance the large number of failures.

BLOSSOM SAND MEMBER OF EAGLE FORD CLAY.

The conditions governing the accumulation of oil and gas in the Blossom sand are more complicated than in the Nacatoch sand, because the Blossom contains more extensive shale beds and is less uniform in texture than the Nacatoch. The shale beds and dense layers in the Blossom sand would interfere with the free movement of gas and fluids, and their distribution may therefore be somewhat irregular. However, the meager information available indicates that the high anticlines would be favorable places to drill for gas in this sand. Oil should be sought near the margin of areas where gas is reported and where showings of oil were encountered in drilling wells to the Woodbine sand.

WOODBINE SAND.

The porosity of the Woodbine sand is so variable that the distribution of oil and gas in the formation is very irregular. This is shown by the partial logs of wells previously given (pp. 49–51) and by the relations of small and large wells, for in many places where wells are only a few hundred feet apart one may have a natural flow of several thousand barrels, whereas those surrounding it and only a few hundred feet away may yield only a few barrels when pumped. There are also marked differences in depths to pay sands and in the depth of salt water sands in wells located close together. Doubtless the connection between the lenticular sands is interrupted in many places by increase in density, but in other places the beds are so discontinuous that oil sands are separated by relatively impervious shales. Under such conditions the accumulation of oil and gas, though in a general way controlled by structure, is influenced by the obstructions to free movements of the gas or liquid through the sand. is, for example, probable that the wells in sec. 4, T. 21 N., R. 16 W.,

owe their success to some obstruction to free movement in a general southeasterly direction. The obstructions in that part of the field may be formed either by a change in the porosity of the sand or a local diminution in its rate of dip of such magnitude that the circulation of liquid through the sand is retarded. Doubtless the distribution of other small pools is controlled in part by obstructions and in part by the existence of minor changes in the dip of the petroliferous sands.

Under the conditions that exist in the Woodbine sand the gas does not all gather at the top of the anticline, as in the Nacatoch sand, but occurs in different places, though it is present in large volume only where the structure is especially favorable, as on the higher anticlines. Both gas and oil are found in the local pools on the slopes of the major anticlines where movement up the slope of the uplift is checked by obstructions such as relatively impervious beds or minor flexures or both.

Under the conditions outlined above exploitation is necessarily hazardous, and structural studies can furnish only the general outlines of the oil pools. Drilling within a pool is uncertain, because the local variations in porosity and dip can only be determined by that method, and where such changes are abrupt the success of one well gives very little clue to the best location for the next. In considering wildcat territory the structure is, however, of primary importance, because only on the crests or borders of uplifts has any considerable volume of oil and gas been found, and only in these localities is it to be expected. The productive part of the uplift will differ in different localities with the height of the structural features, the character of the formation, and the amounts of oil and gas. In many places the structure can be determined by geologic studies, but the other conditions can only be learned by drilling. As a preliminary step the structural studies of the geologist would probably increase the chances of successful selection of territory more than 75 per cent, and such investigations, when made with careful attention to details of structure, should increase the chances of success over 30 per cent in locating wildcat wells. However, it should be borne in mind that to approach these percentages of efficiency familiarity with the local stratigraphy, with the occurrence of oil in the region, and with their relation to each other is essential.

SOURCE OF OIL AND GAS.

THEORIES OF ORIGIN.

The complete discussion of theories of origin of oil and gas would require much greater space than can be given the subject in this report, but it is desirable to present the general principles of the

subject. Two theories have been offered in explanation of the presence of petroleum within the earth: (1) That it is of inorganic origin; (2) that it is of organic origin. In support of the theory of inorganic origin, chemists cite the fact that oil can be produced in the laboratory by the combination of certain inorganic substances. The possibility that favorable conditions for similar chemical action exist deep within the earth furnishes a theme for speculation; but even if such chemical action is conceded a further difficulty is encountered, for in most oil fields free movement of either oil or gas from profound depths into the pay sands is prevented by relatively impervious beds of shale.

In the organic theory of origin processes of slow chemical change are considered to have converted organic matter either into oil or gas, or both. This theory is capable of considerable elaboration and has aroused much controversy as to whether the oil is of animal or vegetable origin. It may be noted here that the organic theory has this advantage—that the source of the oil is considered to be in the sand, or more probably in the formations intimately associated with the sand. This obviates the necessity of extensive migration of the oil and gas through great thicknesses of rock under conditions that in most places may be classed as unfavorable, if not prohibitive.

CADDO OIL FIELD.

The serious objection commonly raised against the theory of inorganic origin, that it is difficult to account for the oil having risen from great depths, is not insurmountable in the Caddo field. If the Red River fault, as described by Veatch, has had a movement of more than 600 feet, the break in the strata must extend to a considerable depth, and upward migration of oil along the fault plane would be possible. Migration of this oil from the fault plane laterally into the porous sands might occur, provided such a movement along the fault plane were once established. However, even if such a migration were proved it would not follow that the oil is of inorganic origin, for it might come from underlying sedimentary rocks.

In the Caddo oil field beds of carbonaceous shales are associated with the oil sands, and the organic matter in these shales and in the sands is a possible source of the oil and gas, and according to this theory the oil may have passed from the shales more or less directly into the sands under the influence of capillarity, gravity, or hydraulic pressure.

In the Nacatoch sand some organic matter existed, and a large amount was disseminated through the overlying Arkadelphia clay. Probably this clay was the principal source of oil, though some might come from beds in the underlying Marlbrook marl. The Blossom

sand member of the Eagle Ford clay may have been supplied from layers of clay interbedded with the sand and from the underlying beds of the Eagle Ford clay, which carry a large quantity of organic matter. The overlying Brownstown marl was probably relatively unimportant. The Woodbine sand is shaly and very carbonaceous and may have supplied a large part of the oil found in the sands, though the Eagle Ford clay, and even the underlying Lower Cretaceoūs, are possible sources of oil and gas.

RELATIONS OF THE OIL AND GAS.

In another part of this bulletin the relative positions of the oil and gas in the producing sands are discussed (pp. 52–55), and it is proposed here to describe briefly the detailed relations and indicate some of the unexplained phenomena.

On the outskirts of the field, both north and west of the producing area, wells encounter small quantities of oil in the Woodbine sand. The depths to the sand are somewhat greater than in localities where successful wells are obtained, and there is a notable difference in the character of the oil. The color of the oil in these wells is commonly light green and the gravity is higher than that of the oil obtained from successful wells; there is also an absence of gas where this high-gravity oil is encountered.

Some differences have been observed in the quality of the gas from the two important producing horizons, the Nacatoch sand and the Woodbine sand. The odor and burning properties of the gases from these sands are unlike, the gas from the Nacatoch sand being practically odorless and the gas from the Woodbine sand having an odor of petroleum. The gas from the Woodbine sand, because of its higher content of hydrocarbons from petroleum, burns with a more pronounced yellow flame than that from the Nacatoch sand.

Practical tests recently made by C. C. Averill, field manager of the Standard Oil Co., have shown that gasoline can be extracted from the gas from the Woodbine sand. Gasoline was produced by subjecting this gas to a pressure of 500 pounds to the square inch and passing it through a coil cooled by water. The pressure used in this experiment is much lower than the rock pressure of the Woodbine sand, and not much greater than the initial rock pressure of 450 pounds of the early gas wells of the Nacatoch sand. It may be inferred that a lower temperature in the Woodbine sand would permit the condensation of the gasoline from the gas.

The gas from the Nacatoch sand did not furnish gasoline when it was subjected to a pressure of 500 pounds to the square inch and cooled in the same manner as that from the Woodbine sand. The oil from the Nacatoch sand is of low gravity and contains a relatively

small percentage of the higher hydrocarbons. This fact, together with the absence of gasoline in the gas from the Nacatoch sand, suggests that there may have been initial differences in the quantities of some of the hydrocarbons in the Nacatoch and Woodbine sands.

The oil found in the Annona chalk and Nacatoch sands is of low gravity and is associated with large volumes of gas. Somewhat similar conditions may be inferred for the Blossom sand member of the Eagle Ford clay, where the oil showings are reported to be of low gravity, though the volume of gas in this sand has not been determined in many wells. Because of the small production, it has been impossible to compare the gas from the Annona chalk and the Blossom sand member of the Eagle Ford clay with the gas from the other sands.

POSSIBLE EXTENSIONS OF THE CADDO OIL FIELD.

The history of development in the Caddo oil field, characterized by many rapid fluctuations in the amount of production, has demonstrated that in many places valuable territory has existed where operators have thought the conditions unfavorable. No one familiar with the field can doubt that there is still much unexploited territory within the boundaries of the field, though the cost of drilling combined with the uncertain results, even in proved territory, should be taken into consideration before investing blindly in oil properties.

As noted by Harris,[1] there appears to be a broad syncline between the northern edge of the Caddo oil field and Texarkana (fig. 4, p. 34). This syncline carries the oil-bearing formations to a much greater depth than that in the oil field, and though minor flexures may be expected in the syncline it is somewhat doubtful whether they would supply enough oil to warrant drilling, even where showings might be obtained.

Veatch[2] has mentioned a large fault that extends in a general direction south of east into northwestern Louisiana and cuts across this syncline. This fault, as shown on Veatch's map, would follow approximately the course of Sulphur River. During the field work for this report it was not possible to make an examination of the region where the fault is shown on Veatch's map, and it should be noted that Harris's diagram (fig. 4) indicates no fault in that region. On the whole it appears desirable to examine further that part of the syncline to determine the structural features and what value

[1] Harris, G. D., Oil and gas in Louisiana, with a brief summary of their occurrence in adjacent States: U. S. Geol. Survey Bull. 429, p. 125, 1910.

[2] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 68, 1906.

they may have in connection with the occurrence of oil and gas in sufficient quantities to warrant drilling.

Since the preparation of Harris's report drilling has ceased in the syncline, as the results obtained do not seem to warrant further expenditure of money. On the west side of the Caddo field much less information is afforded by well logs than on the north side. It should be possible to extend the western margin of the field a short distance into Texas at places where the sands are high, and the trend of development has already carried the edge of the field a short distance beyond its location when the field work for this report was in progress. The most promising territory for development lies at the western ends of the major anticlines, such as those north of the Burr pool, a short distance south of this pool, and near the Atlas Oil Co.'s wells, and farther south in Caddo Lake and along its shores near the Texas-Louisiana boundary.

The pitch of the Caddo Lake anticline and of the minor anticlines that parallel it on the north and south has not been determined with sufficient accuracy to warrant a prediction as to just how far development may be successful. For this reason conservative progress can best be made by gradual extension toward the west, as in the recently located wells in and near Caddo Lake in Texas and the well of the Atlas Oil Co. just north of Caddo Lake in Louisiana. By this method it should be possible to determine the limits of the producing territory with a minimum expenditure of funds for dry holes. Since the Caddo Lake anticline is the highest in the field it may be expected to extend farther west from its apex than any of the other folds, but this does not necessarily mean that successful wells can be obtained beyond the Texas boundary, because the apex of this fold lies somewhat farther east than the apexes of other folds north of the lake.

Though the dip of the formations on this side of the field is toward the west, they rise again a short distance farther west and reach the surface in northern Texas. Little is known about the detailed structure of the region between the outcrop and the west edge of the Caddo field, however, and this is an area that is worthy of further study to determine whether there are other folds similar to those found in northwest Louisiana.

Harris[1] states that on the south side of the Caddo oil field there is a shallow syncline (fig. 4, p. 34) that occupies the territory between Mooringsport and Shreveport. The information then available would naturally lead a geologist to this conclusion; however, it is doubtful if this syncline continues throughout the distance between

[1] Harris, G. D., Oil and gas in Louisiana, with a brief summary of their occurrence in adjacent States: U. S. Geol. Survey Bull. 429, p. 127, 1910.

these two points. More probably there are other anticlines parallel to those at Shreveport and Mooringsport, though no great amount of success has been achieved by drilling in this region up to the present time. It is hoped that in the near future it will be possible to make a thorough investigation of the structure in this area to warrant drawing definite conclusions.

On the east side of the Caddo oil field drilling has been successful in the shallow (Nacatoch) sand at the east end of the Vivian anticline. There is still considerable territory on the east and south sides of this anticline that might warrant drilling for heavy oil. Farther south the most promising territory so far discovered is in the vicinity of Dixie, where some wells have encountered a fair amount of oil in the Woodbine sand. There is doubtless much territory between these wells and the pools at Caddo Lake that will prove valuable for oil.

East of Red River, in Bossier Parish, a number of wells have been drilled, and although small quantities of oil have been encountered and good thicknesses of oil sand are reported, none of the wells have been successful. From the meager information at hand concerning this area the most promising territory should be near the river and slightly north of east from the high structures of the field in Caddo Parish. The success of wells near the river will depend on whether the sands of the Caddo field continue high and are petroliferous. The absence of good exposures of the older geologic formations makes it impossible to determine the structure in the river valley, and the presence or absence of oil in the sands can only be ascertained by drilling.

Possibly some deep wells might be moderately successful near the eastern edge of the Sabine uplift, which is near the boundary between the Wilcox formation and the more ferruginous beds of the Claiborne formation. The approximate position of this boundary is shown on Plate XII of Bulletin 429. If oil is discovered near the contact of the Midway and Claiborne formations the pools will probably be small and the sands will be deeper than in the Caddo field.

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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, Director

Bulletin 620

CONTRIBUTIONS TO ECONOMIC GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1915

PART I.—METALS AND NONMETALS EXCEPT FUELS

F. L. RANSOME AND HOYT S. GALE

GEOLOGISTS IN CHARGE

WASHINGTON

GOVERNMENT PRINTING OFFICE

1916

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[Arranged according to subjects.]

ILLUSTRATIONS.

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1915.

PART I. METALS AND NONMETALS EXCEPT FUELS.

F. L. RANSOME and HOYT S. GALE, *Geologists in charge*.

INTRODUCTION.

This volume is the thirteenth of a series that includes Bulletins 213, 225, 260, 285, 315, 340, 380, 430, 470, 530, 540, and 580, "Contributions to economic geology" for 1902, 1903, 1904, 1905, 1906 (Pt. I), 1907 (Pt. I), 1908 (Pt. I), 1909 (Pt. I), 1910 (Pt. I), 1911 (Pt. I), 1912 (Pt. I), and 1913 (Pt. I), respectively. These bulletins are prepared primarily to insure prompt publication of the economic results of investigations made by the United States Geological Survey. Beginning with the present volume the year included in the title will be the year of publication[1] instead of the year in which the field work reported was done. This volume is therefore dated 1915, and there will be no volume entitled "Contributions to economic geology, 1914."

As the subtitle indicates, the papers included are of two classes—(1) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of sufficient importance to warrant a more extended description; (2) preliminary reports on economic investigations the results of which are to be published later in more detailed form. These papers are such only as have a direct economic bearing, all topics of purely scientific interest being excluded. Each paper has been issued as an advance chapter as soon as it was ready.

Brief abstracts of the publications of the year are given in the annual report of the Director. The complete list of Survey publications affords, by means of finding lists of subjects and of authors, further aid in ascertaining the extent of the Survey's work in economic geology.

Since 1905 the annual economic bulletin has been printed in two parts, the second part comprising papers on mineral fuels. These

[1] Owing to unexpected delays in printing some of the maps it has been impossible to publish all the chapters of this bulletin in 1915.

volumes for 1906, 1907, 1908, 1909, 1910, 1911, 1912, and 1913 are Bulletins 316, 341, 381, 431, 471, 531, 541, and 581. Bulletin 621 forms Part II of the "Contributions" for 1915.

The reports on work in Alaska have been printed in a separate series since 1904, the volumes so far issued being Bulletins 259, 284, 314, 345, 379, 442, 480, 520, 542, 592, and 622.

A GOLD-PLATINUM-PALLADIUM LODE IN SOUTHERN NEVADA.

By Adolph Knopf.

INTRODUCTION.

The discovery of platinum-bearing gold ore at the Boss mine, in southern Nevada, was brought to the attention of the Geological Survey by Mr. F. A. Hale, jr., in September, 1914. Some samples of the ore were submitted at the same time. These were assayed and found to be extraordinarily rich in gold, platinum, and palladium. A brief announcement of the discovery, based on the returns of these assays and on information courteously supplied by Mr. Hale, appeared on October 3, 1914, in an advance chapter of Mineral Resources [1] for 1913. Early in October an examination of the deposit was made by the writer, the results of which are here given.

LOCATION.

The Boss mine is situated in the Yellow Pine mining district, Clark County, Nev., near the extreme southern part of the State. The main settlement of the district is Good Springs, distant 8 miles from Jean, a station on the San Pedro, Los Angeles & Salt Lake Railroad. Good Springs lies on the east side of a desert range known as Spring Mountain, but the mine is situated on the west slope, 12 miles from Good Springs, by a road which crosses the range through a low pass. A few miles from the mine is the abandoned settlement known as Sandy (Ripley post office), at which was situated the cyanide plant of the Keystone mine. From a well at this place water of good quality is obtained for domestic use at the Boss mine and neighboring prospects. An ample supply is said to be available for milling purposes.

HISTORY.

The deposit on the Boss claim was discovered some 30 years ago, having been located for copper, the presence of which is plainly indicated by chrysocolla and other oxidized copper minerals. In

[1] Day, D. T., The production of platinum and allied metals in 1913: U. S. Geol. Survey Mineral Resources, 1913, pt. 1, pp. 448-450, 1914. A more detailed account was published by Mr. Hale (Platinum ore in southern Nevada: Eng. and Min. Jour., vol. 98, pp. 641-642, 1914).

the nineties the property was bonded and a leaching plant was built at Good Springs to treat the oxidized copper ores, but, the process proving a failure, the property reverted to its original owners. Not until recently has the gold and platinum content of the ore been recognized. The owners, Messrs. Yount & White, discovered the high gold content by sampling and assaying, and the Boss Gold Mining Co. was organized in March, 1914.

The failure to recognize previously the auriferous character of the ore needs explanation. It seems to have been due in part to the fact that, although the ore can be shown by assays or chemical means to carry considerable gold, the presence of the gold, as the writer has verified personally, is not evident on panning. Moreover, some extraordinarily rich material (the plumbojarosite, described on p. 8, assaying as high as $6,000 to the ton in gold) yields when panned a black residue which might easily be thrown away as worthless black sand. This unpromising-looking black residue when strongly scoured by rubbing it in the pan with a piece of iron rolls out into yellow flakes and quills, and its identity as gold becomes manifest. The discovery of the platinum content of the ore is due to the acumen of Mr. H. K. Riddall, chemist for the Yellow Pine Mining Co. In running assays of the Boss ore he noticed that the gold buttons, instead of being smooth, had rough, cauliflower-like surfaces. He suspected that the buttons might contain platinum, and this suspicion was strengthened by the fact that solutions obtained on parting, instead of being colorless as is the rule when the gold is alloyed with silver only, showed yellow and brown tints, indicating the presence of platinum and palladium. By systematic tests these metals were then proved to be present. This result was soon verified by a number of other assayers, although one supposedly reliable assaying firm in Los Angeles reported that the ore contained no platinum. Two samples sent to the Geological Survey by Mr. Hale were submitted for assay to Ledoux & Co., of New York, who reported on September 9, 1914, as follows:

Assays of ore from Boss mine.

	1	2
	Ounces.	*Ounces.*
Platinum	7.38	99.08
Gold	11.55	111.00
Palladium	....	16.00

NOTE.—Concentration by panning shows that the metals are in the free state, being apparently alloys of gold and platinum metals. Owing to uneven distribution, assaying is very difficult and the above results can only be considered as approximately correct. Assay for palladium was omitted on No. 1, but the sample contains 1 or 2 ounces of this metal. A little iridium is present in No. 2.

Prior to the discovery of the platiniferous character of the ore some small shipments of high-grade copper ore and of high-grade

gold ore had been sent to the smelter at Salt Lake City, but after the platinum content was recognized production was suspended, pending arrangement for the advantageous disposal of the platinum and allied metals.

In October negotiations were under way for the treatment of certain lots of high-grade ore by the Pacific Platinum Works, of Los Angeles, whereby this firm agreed to pay $46 an ounce for the combined platinum and palladium content, after deducting a treatment charge of $300 a ton.

Late in the year the mine was sold by the Boss Gold Mining Co. to W. C. Price and associates for $150,000, according to O. J. Fisk, former manager of the company.

The great interest that attaches to so unusual and remarkable an occurrence of platinum and palladium in a gold-bearing lode hardly needs comment. As is shown on pages 13–17, in the review of the known distribution of platinum in veins, the Boss vein is one of the few primary deposits in which metals of the platinum group occur in more than traces and, with one possible exception (the New Rambler mine in Wyoming), is the only primary deposit of economic importance in which these metals are the constituents of predominant value.

GENERAL GEOLOGY OF THE DISTRICT.[1]

SEDIMENTARY AND IGNEOUS ROCKS.

The prevailing rocks of the district are stratified dolomites of middle Carboniferous age. (See Pl. I.) They are considerably though not acutely folded and are broken by faults. This formation is economically the most important assemblage of rocks in the district, as all of the ore deposits occur in it or in the dikes cutting it.

Limestones of Pennsylvanian age and red sandstones and shales of probable Mesozoic age are also present in the district, but they are of no special concern here, as they lie at a considerable distance from the area in which the Boss mine is situated.

Intrusive igneous rocks are not common in this district; in fact, the areas occupied by them are so small as to be barely perceptible on the geologic map. They consist of sills and short dikes of quartz monzonite porphyry and granite porphyry, as a rule considerably altered. The age of intrusion has not been established, but is thought to be at least as recent as post-Jurassic.

Some horizontal sheets of biotite andesite cap the summit of Table Mountain, southwest of Good Springs. This is the only noteworthy occurrence of extrusive rocks in the district.

[1] A more extended discussion of the geology is given by J. M. Hill: The Yellow Pine mining district, Clark County, Nev.: U. S. Geol. Survey Bull. 540, pp. 223–240, 1914.

METALLIFEROUS FEATURES.

The principal metalliferous deposits of the district are bodies of lead-zinc ores inclosed in dolomite or limestone. The prevailing minerals are smithsonite and cerusite; galena occurs to some extent, but zinc blende, presumably the parent of the oxidized zinc ores, is present in only one mine. The genesis of the primary minerals of these deposits is as yet unknown.

Gold deposits were formerly of some importance in this district, the Keystone mine, the most productive, being credited with an output of $1,000,000. At this mine the gold is disseminated through quartz monzonite porphyry, which has been highly altered by the development of sericite and siderite. In general the deposits are closely associated with the porphyry dikes and may stand in genetic relation to them. Certainly the chemical alteration produced in the porphyry dikes indicates that the ore-forming solutions were ascending thermal waters.

Some copper deposits have also been developed. They consist predominantly of oxidized copper minerals forming irregular replacement bodies. Tetrahedrite, which has been recognized in the gold ore of the Lavina mine, and chalcocite are the only copper-bearing sulphides found in the district.

Finally, brief mention should be made of the so-called vanadium deposits. On the Bill Nye claim, for example, a dolomite breccia cemented by a copper-bearing lead vanadate, probably cuprodescloizite, forms a tabular deposit 18 to 24 inches thick, which has been exposed by an incline to a depth of 12 feet.

The Yellow Pine district is the most productive zinc and lead district in Nevada. In 1913 it yielded 29,060 tons of ore, containing $1,268 in gold, 192,339 ounces of silver, 283,592 pounds of copper, 6,204,065 pounds of lead, and 14,369,709 pounds of zinc, valued in all at $1,239,081.[1]

THE BOSS MINE.

GENERAL GEOLOGIC FEATURES.

The country rock at the Boss mine consists of dolomite in beds ranging from a few inches to several feet thick. The beds comprise a dark-gray or black variety, fetid with hydrogen sulphide on fresh fracture, and a more prevalent pale-buff variety. They not uncommonly carry crinoid fragments and are of late Mississippian or early Pennsylvanian age—that is, middle Carboniferous.

The rocks strike east and dip gently to the north. The structure is that of a broad anticlinal arch, whose crown has been more or less

[1] U. S. Geol. Survey Mineral Resources, 1913, pt. 1, p. 818, 1914.

fractured and broken by faults. In the immediate vicinity of the mine the rocks are practically horizontal.

A small mass of granite porphyry or dike of no great linear persistence occurs 600 feet north of the mine. This rock is characterized by numerous large corroded phenocrysts of quartz and kaolinized feldspars embedded in a fine-grained groundmass. It accordingly resembles the small masses of intrusive granite porphyry and quartz monzonite porphyry scattered throughout the district. The porphyry is highly altered and has been considerably prospected for gold, but has proved of too low grade to be profitable, carrying at best only a few dollars in gold to the ton.

The ore bodies so far developed may be briefly characterized as oxidized copper shoots and gold-platinum-palladium shoots. The copper ores consist largely of chrysocolla and colloidal complexes of chrysocolla and limonite; these ores are reported to carry only minor amounts of the precious metals. The gold-platinum-palladium shoots consist of fine-grained siliceous ore carrying a small quantity of a bismuth-bearing variety of plumbojarosite (a hydrous sulphate of iron and lead). There is no fixed ratio between the content of gold and the platinum metals, nor between the content of platinum and palladium. This variability seems to be a result of the prevailing oxidized condition of the ore. The palladium, according to reliable figures furnished to the writer, is probably in excess of the platinum.

The copper shoots and the precious-metal shoots can be mined separately, it is said. The segregation of the metals into separate shoots that makes this feasible will assuredly be found less and less complete as depth is attained on the deposit.

The ore bodies of the Boss mine occupy a nearly vertical zone of fracturing in the horizontal strata of dolomite. At the surface this zone is 30 feet wide, but the precious-metal shoots are confined to the 12 feet resting on the footwall. The length of the mineralized zone exposed on the surface is about 100 feet, but the ore bodies do not extend continuously over this distance. At the portal of the upper tunnel the footwall strikes N. 5° E. and the hanging wall strikes N. 25° E. The principal ore shoot, so far as the present workings disclose, forms an irregular pipe pitching at a low angle to the northeast.

The dolomite within the zone of fracturing has recrystallized to a coarse white spar, and this dolomite spar makes up the rock inclosing the ore shoots.

DEVELOPMENT.

The principal development consists of three tunnels driven along the zone of mineralization. (See fig. 1.) They are known as the upper, middle, and lower tunnels. The middle tunnel is about

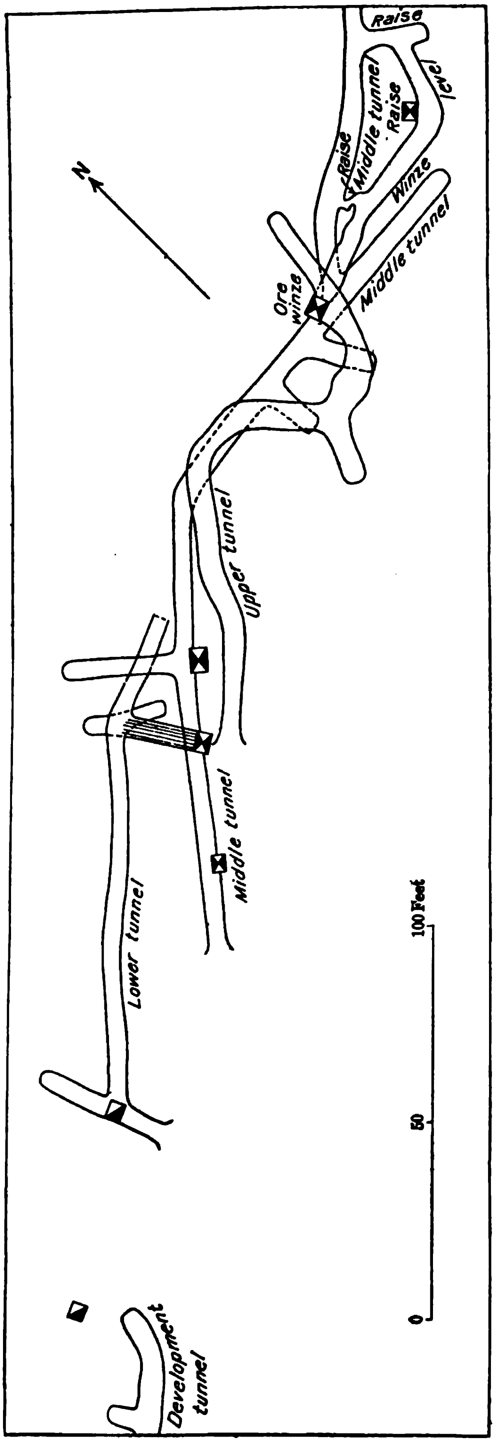

FIGURE 1.—Plan of the workings of the Boss mine, Clark County, Nev.

30 feet below the upper, and the lower is about the same distance below the middle tunnel. The richest ore is exposed in the "ore winze," which was sunk from the upper tunnel and is connected with the middle tunnel. Estimates of the total amount of ore exposed in the mine range from 1,000 to 2,000 tons, but at the time of visit an accurate estimate was not possible.

A development tunnel was started some years ago several hundred feet below the upper group of tunnels, but no work has been prosecuted on it recently.

MINERALOGIC FEATURES.

The essential features of the deposit are well shown in the irregular open cut at the portal of the upper tunnel. Here there is a considerable mass of somewhat cupriferous gossan. Below it, at about the tunnel level, is an irregular pocket of light-gray material, which crumbles to a fine gray sand; and beneath this sandy material is a porous dark-gray to blackish siliceous rock. The ore carries gold and platinum metals, and a winze was sunk

here to the tunnel below, but the ore shoot is reported not to have persisted to the lower level. About 6 feet farther in toward the mouth of the tunnel, lying under a mass of earthy red hematite, is another streak of gray sandy material, containing a middle band, three-fourths of an inch wide, of a soft greenish-yellow powder. This greenish-yellow mineral, identified as a new variety of the rare species plumbojarosite, is extraordinarily rich in gold and platinum metals; in fact, the evidence indicates that the distribution of the precious metals, especially of those of the platinum group, is dependent on the presence of this mineral.

A sample of the gray sandy material essentially free from admixed plumbojarosite, taken by the writer from a point near the winze mentioned above, was submitted to the Bureau of the Mint and assayed by F. P. Dewey, who reports as follows: Gold, 0.44 ounce to the ton; platinum metals remaining insoluble on boiling the silver lead in strong sulphuric acid, 0.01 ounce to the ton. If palladium was present it was not determined.

The gray sandy material proves to consist largely of perfectly formed crystals of quartz, averaging 0.1 millimeter in diameter; doubly terminated crystals are common. Some of this quartz sand, after repeated evaporation with hydrofluoric acid, left a small residue consisting of minute crystals of adamantine, almost metallic luster. These crystals comprised octahedrons and square tabular forms, averaging a few hundredths of a millimeter in size. Their crystal habit, together with the fact that they gave a strong titanium reaction after fusion with potassium bisulphate, suggested that they were octahedrite (anatase), and their identity as octahedrite was conclusively established by Dr. H. E. Merwin by the determination of their optical properties. Dr. Merwin reports as follows:

The grains are mostly single crystals, slightly tabular normal to an optic axis (uniaxial, negative). The refractive index ω was found to be $2.51+0.01$ for lithium light. Measured on six crystals, $\omega-\epsilon$ is $0.070+0.003$. The value for ω is the same as all observers have found for anatase (ranging between 2.515 and 2.521) and $\omega-\epsilon$ is the same as later investigators have found for this mineral (0.066–0.073).

A few prisms and knee-shaped twins of rutile occur with the octahedrite. The octahedrite and rutile are subordinate constituents, but they are the only gangue minerals in the deposit other than quartz.

A particularly rich shoot of ore has been developed by a winze sunk from a point near the end of the upper tunnel. In this shoot are small masses of what is locally known as greenish talc.[1] Some of these were mined separately and two shipments aggregating about 1 ton were sent to the smelter at Murray, Utah. On a control sample of this ore Ledoux & Co. report as follows: Gold, 111 ounces to the

[1] Hale, F. A., Eng. and Min. Jour., vol. 98, p. 642, 1914.

ton; platinum, 99.08 ounces to the ton; palladium, 16 ounces to the ton; iridium, trace.

The "greenish talc," determined chemically and microscopically, proves to be a bismuth-bearing variety of the rare mineral plumbojarosite. It is a greenish-yellow mineral of smooth, unctuous feel, which under the highest power of the microscope is seen to consist of perfect hexagonal tablets averaging 0.01 millimeter in diameter. It carries considerable mechanically admixed gold and platinum metals. An analysis of the purest obtainable material was made in the laboratory of the United States Geological Survey by R. C. Wells, with the following results:

Analysis of bismuthic plumbojarosite from the Boss mine.

Fe_2O_3	32.24	CaO	0.06	TiO_2	0.37
Al_2O_3	.14	MgO	.14	Au	.79
SO_3	24.08	K_2O	.22	Pt	.05
PbO	16.75	Na_2O	.52	Pd	.22
H_2O-	.02	CO_2	.43	Ir	Trace.
H_2O+	8.55	As_2O_5	.09	Ag	Trace.
CuO	1.97	P_2O_5	Trace.		
Bi_2O_3	6.34	SiO_2	6.90		99.88

Reduced to ounces a ton, the analysis shows gold to be present to the extent of 234 ounces, platinum 15 ounces, and palladium 64 ounces. Assays of similar material are reported to show as high as 575 ounces of gold, 230 ounces of platinum, and 30 ounces of palladium. The silica and titania shown by the analysis represent an admixture of quartz and octahedrite.[1]

The gold and platinum metals can be partly separated from the plumbojarosite by panning, but long before a clean separation can be effected fine gold and especially platinum pass into the tailings, in spite of the utmost precaution. The gold is extraordinarily rough and spongy; delicate platy forms are common, and some is intergrown with quartz and plumbojarosite or is molded around minute quartz crystals. It is more or less blackish, and aggregates of the finer particles look like so much black sand. Treatment with hydrochloric acid and annealing, however, bring out the normal yellow color of gold. Some of the larger particles after being treated thus were analyzed by R. C. Wells, as follows:

Analysis of gold from the Boss mine.

Gold	97.8
Silver	2.2
Platinum metals	Trace.
	100.0

[1] Further study of the material analyzed shows that it contains 20 per cent of beaverite, $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$. (See Knopf, Adolph, Plumbojarosite and other basic lead-ferric sulphates from the Yellow Pine district, Nev.: Washington Acad. Sci. Jour., vol. 5, pp. 497-503, 1915.)

Qualitative tests on other gold particles always showed the absence of platinum metals, and the inference of Ledoux & Co. that the metals are present "apparently as alloys of gold and platinum metals" is therefore not borne out. The platinum and palladium occur in extremely small particles, which even at high magnification under a binocular microscope are indistinguishable from the dull blackish particles of gold; in all material examined by the writer chemical tests were necessary to establish the presence of the platinum and allied metals. By cleaning the precious metals in molten sodium carbonate, particles of gray metal (platinum and palladium, or an alloy of these) become distinguishable from yellow gold. The possibility was entertained that sperrylite might be present in the residue of the pannings from the plumbojarosite or elsewhere in the ores of the Boss mine, but no trace of this mineral, which, according to its discoverer, is characterized by a wonderfully brilliant luster, was found.

The pockets of plumbojarosite occur in a porous, fine-grained siliceous gangue, which is a replacement of the dolomite country rock. The pores and cavities evidently resulted from the leaching of sulphides formerly present; they are now partly filled with malachite in small botryoidal groups, or more commonly with powdery plumbojarosite. A thin section cut from a specimen selected for assay shows quartz, commonly euhedral, and plumbojarosite scattered throughout the material, perhaps to the extent of 10 per cent. This specimen was submitted to the Bureau of the Mint for assay, and F. P. Dewey reports as follows:

> Gold, 4.12 ounces to the ton; platinum metals remaining insoluble on boiling the silver bead in strong sulphuric acid, 3.35 ounces to the ton. I made no determination of palladium, but the sulphuric-acid solution was strongly colored, indicating that much palladium had gone into solution.

This determination of the platinum metals (mainly platinum with some iridium) is therefore a minimum for this particular sample. The ore, despite its extreme richness, shows no free gold or platinum metals. The writer was unable to pan any precious metal from this ore, or to separate any with heavy solution, but on evaporation with hydrofluoric acid an extremely fine black residue remained, containing gold, platinum, palladium, and octahedrite.

A composite of 22 samples taken in the winze connecting the upper and middle tunnels and on the intermediate level yielded the following return, in ounces to the ton: Gold, 3.46; silver, 6.4; platinum, 0.70; palladium, 3.38.[1] It is probable that there are several hundred tons of ore of this grade, which, with platinum and palladium at $45 an ounce, has a value of $256 a ton.

[1] Data furnished to the writer by a mining engineer who examined the mine under an option that was not exercised.

The only sulphide-bearing ore exposed in the mine at the time of visit was in the sublevel below the upper tunnel. Here, in particularly tight ground, about 3 feet of copper ore rich in chalcocite had been opened. An average sample of this ore, as reported by the management, showed copper 15.1 per cent and platinum metals 0.40 ounce, gold 0.13 ounce, and silver 1.2 ounces to the ton.

The chalcocite, which is of the steely kind and shows conchoidal fracture, occurs as small blebs and finely disseminated particles embedded in a close-grained siliceous gangue. It is partly altered to brochantite, the basic sulphate of copper, which forms small glassy emerald-green prisms implanted on the sulphide from which it was derived. Examination of this ore under the microscope shows that it is an aggregate of quartz, chalcocite, and brochantite, with octahedrite present as a rare accessory mineral; the brochantite occurs in partial replacement of the quartz and is somewhat more abundant than would be estimated from inspection by the unaided eye. An oxidized bismuth compound, whose identity was not established, is associated with some of the chalcocite.

GENESIS OF THE ORE.

The Boss deposit represents in the main an irregular siliceous replacement of dolomite along a series of vertical fractures. On account of the prevalent oxidation and the inconsiderable depth to which the workings have penetrated, primary sulphides have not yet been reached. The chalcocite, the only sulphide so far found, most probably originated as a precipitate from downward-moving solutions whose copper was derived from primary sulphides formerly exposed to oxidation near the surface.

The deposit yields as yet no especially strong evidence concerning the genetic conditions that prevailed at the time it originated. Some clue is perhaps afforded by the presence of the titanium oxide minerals, octahedrite and rutile. Both of these are rather uncommon in metalliferous deposits. Of the two rutile is the more common. It is, for example, somewhat abundant in certain of the auriferous deposits of the Juneau gold belt, which are veins that originated at high temperature; in fact, according to W. H. Emmons,[1] rutile is restricted to high-temperature veins. Octahedrite occurs in the tourmaline-bearing copper veins of Las Condes, Chile;[2] in tin veins of Saxony associated with apatite, fluorite, and chlorite; and in fissure fillings in the Alps,[3] but these veins are not notably metalliferous. The Alpine veins are thought to have formed at tempera-

[1] A genetic classification of minerals: Econ. Geology, vol. 3, p. 625, 1908.

[2] Lindgren, Waldemar, Mineral deposits, p. 655, 1913.

[3] Koenigsberger, Johann, Transformations and chemical reactions in their application to temperature measurement of geologic processes: Econ. Geology, vol. 7, p. 697, 1912.

tures between 250° and 400°. In view of the affiliation generally shown by the octahedrite and rutile with deposits of high-temperature origin, the suggestion is advanced that the primary ore of the Boss deposit was formed under conditions of moderately high temperature.

The facts at hand can not of themselves be held to prove that the ore deposition was genetically connected with the intrusion of any particular dike or igneous mass now visible at the surface. It is probable, nevertheless, that the mineralization followed as a sequel to the intrusion of the magma from which the granite porphyry dikes were derived, for these are the only intrusives that penetrate the rocks of the district.

The deposit, as already described, is highly oxidized and contains abundant oxidized copper compounds and plumbojarosite. These minerals indicate that the primary sulphides will be found to carry copper, iron, lead, bismuth, and precious metals. The extraordinary richness in gold, platinum, and palladium of ore containing notable quantities of plumbojarosite raises an important problem. It is of course not impossible that the plumbojarosite may have originated essentially in place by simple oxidation of sulphides that were extremely rich in precious metals. A partial analogy for this supposition is furnished by the development of the brochantite in the chalcocite-bearing ore; the brochantite appears to have formed in place from the chalcocite without any important migration of copper. For the origin of the plumbojarosite, however, the following explanation appears to fit the known facts more closely. B. S. Butler,[1] who has recently shown that in the oxidized ores of Utah plumbojarosite is rather common, although heretofore unrecognized, believes that in the occurrences studied by him the plumbojarosite was produced by the action of ferric solutions on galena; the lead has remained essentially in place, but the iron may have come from some distance. It is therefore suggested that in the Boss ore body descending solutions rich in ferric sulphate attacked primary galena, forming the plumbojarosite, and that this reaction caused the concomitant precipitation of the gold, platinum, and palladium. According to this explanation an efficient solvent for the precious metals was active and in this connection the fact established by R. C. Wells, during the chemical investigation of the plumbojarosite, that the precious metals are rather soluble in hydrochloric acid in the presence of plumbojarosite is highly suggestive.

On the whole, then, it is likely, in view of the probable mode of origin of the plumbojarosite and of the evidence of leaching indicated by the porous nature of the siliceous ore, that a certain amount of redistribution of gold, platinum, and palladium has taken place by

[1] Occurrence of complex and little-known sulphates and sulpharsenates as ore minerals in Utah: Econ. Geology, vol. 8, pp. 315-316, 1913.

the action of descending surface solutions. It would follow, then, that in depth, below the zone of oxidation, the pockets of extremely high-grade ore, such as are now being extracted, will be found to give way to ore of moderate grade.

AZURITE MINING CO.'S CLAIMS.

The claims of the Azurite Mining Co. adjoin those of the Boss group, and some work is in progress here. The Rosella prospect, situated several hundred feet north of the Boss mine, is in a coarsely crystalline white dolomite; the metalliferous deposits consist of small irregular bodies of oxidized lead-zinc ore. Of interest is the occurrence of pure lumps of the rare mineral plumbojarosite, consisting of minute hexagonal tablets, having a maximum refractive index of 1.83, and reacting for lead, ferric iron, water, and sulphate. Curiously enough the plumbojarosite is not a bismuth-bearing variety, as at the adjoining Boss mine. In places a porous siliceous gangue is found, but this has not been shown to be platiniferous.

On the Azurite claim a body of oxidized copper ore inclosed in coarsely crystalline dolomite has been opened. The gangue is siliceous and, in addition to carrying the oxidized copper minerals, locally contains chalcocite.

ORO AMIGO MINE.

At the time of the writer's visit to the Yellow Pine district, metals of the platinum group were known to occur only at the Boss mine. Since then they have been found in the ore of the Oro Amigo mine, the property of the Oro Amigo Platino Mining Co., which is situated between 1 and 2 miles northeast of the Boss mine. Mr. H. K. Riddall, to whom the writer is indebted for specimens of the ore, reports as follows:

Assay of ore from Oro Amigo mine.

[Ounces to the ton.]

	Gold.	Platinum metals.
Sample No. 1, width 3 feet	0.11	0.10
Sample No. 2, width 6 inches	.51	Small.

Sample No. 1, as examined by the writer, consists essentially of limonite; it carries no bismuth nor admixed plumbojarosite and is therefore quite unlike the ore of the Boss mine. This may indicate that the distribution of the platinum metals is more widespread in the Yellow Pine district than is now known and that it is not restricted to the peculiar mineral association shown by the Boss deposit. Sample No. 2 is a siliceous rock, holding numerous small angular fragments of chert, and is coated and permeated with limonite.

GEOLOGIC OCCURRENCE OF PLATINUM.

REVIEW OF KNOWN LODE OCCURRENCES.

To afford a basis for comparison of the platiniferous deposit at the Boss mine with other occurrences of platinum in lodes, a short summary is given in the following pages, describing, so far as they are known, the geologic features of some of the more important occurrences of platinum in lode deposits.

The bulk of the world's supply of platinum, as is well known, is obtained not from lodes but from placers, those in the Ural Mountains of Russia alone furnishing 95 per cent of the entire annual production. Minor quantities are derived from Colombia, California, and New South Wales. In the Ural Mountains the platinum-bearing gravels have resulted from the erosion of a broad belt of basic plutonic rocks trending parallel to the axis of the range.[1] The platinum, traced to its bedrock source, is found as an original constituent of dunite, or rarely of pyroxenite, and as such has crystallized from a molten state, most commonly in association with chromite. The metal occurring thus, however, is too dispersed to be economically valuable. Certain segregations of chromic iron in the dunite contain considerable amounts of platinum, but even these are so small and irregularly distributed that they do not admit of profitable exploitation. The output of platinum in the Ural region is therefore derived solely from the placers. These are now worked mainly by dredges, and this industry is regarded as likely to show an expansion in the future.[2]

The platiniferous gravels of other districts, such as those of Colombia, have essentially the same geologic relations as those of the Ural Mountains. The platinum obtained as a by-product of the gold-dredging industry of California is shown by Lindgren [3] to be derived from the erosion of the serpentine, peridotite, and gabbro masses occurring in the auriferous region.

Although platinum occurs in metalliferous lodes at a number of places in several parts of the world, no lode deposit is worked solely for its platinum content. In fact, the platinum in those deposits from which it is obtained forms but an insignificant fraction of the total metallic content, either in quantity or in value, and is recovered as a minor by-product. There are, however, a few platiniferous lode deposits which, under more favorable commercial conditions, may possibly become productive and in which the platinum is the metal of predominant value.

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[1] Duparc, Louis, Le platine et les gîtes platinifères de l'Oural: Arch. sci. phys. nat., vol. 31, 1911; reviewed by E. S. Bastin in Econ. Geology, vol. 7, pp. 202-203, 1912.

[2] Hutchins, J. P., Dredging in the Russian Empire: Eng. and Min. Jour., vol. 98, p. 857, 1914.

[3] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, p. 74, 1911.

Platinum and palladium occur in the copper-nickel ore of the Sudbury region, Canada, and small quantities of these metals are recovered annually from the electrolytic muds formed during the refining of the nickel. In 1902 no less than 2,375 ounces of platinum and 4,411 ounces of palladium were recovered, but the production has since decreased very considerably, and no figures are available for the years after 1904.[1] The platinum occurs in the ores of the Sudbury region as the arsenide, sperrylite, the only known natural compound of the metal. This mineral was, in fact, first discovered in the gossan of the Vermilion mine. Although palladium is present in larger amounts than platinum, no palladium compound has yet been recognized.[2] Sperrylite forms small cubes and octahedrons of brilliant tin-white color and resists weathering completely; hence it becomes concentrated in the gossans of the oxidized sulphide masses.[3] In the unoxidized ore it is associated mainly with chalcopyrite, from which it can be isolated by treatment with acid. The Sudbury deposits, consisting of pyrrhotite, pentlandite, and chalcopyrite, resulted from the separation of these minerals from a body of molten rock before cooling was complete; the associated platinum and palladium are therefore of direct magmatic origin.

Sperrylite has also been recognized in the ore of the Rambler mine, Wyoming.[4] The deposit consists of covellite, chalcopyrite, chalcocite, and pyrite inclosed in a highly decomposed diorite. The sperrylite is particularly associated with the covellite in extremely minute crystals, the largest isolated by Wells and Penfield[5] measuring only 0.12 millimeter in diameter. Considerable palladium is associated with the platinum. A special investigation was made by T. T. Read[6] to determine the condition in which this palladium occurs in the ore. He concluded that it is either in the tetrahedrite, which he showed is a constituent of the Rambler ore, or may be present as some definite palladium mineral soluble in nitric acid or caustic soda. No evidence was obtained that the palladium is present as an arsenide analogous to sperrylite. In recent years an experimental mill has been built at the Rambler mine and the recovery of the precious metals attempted.[7] In 1911 an initial production of about 60 ounces

[1] Coleman, A. P., The nickel industry; with special reference to the Sudbury region, Ontario, pp. 109-110, 1913.

[2] Idem, p. 29.

[3] Idem, pp. 44-55.

[4] Kemp, J. F., Platinum in the Rambler mine, Wyoming: U. S. Geol. Survey Mineral Resources, 1902, pp. 244-250, 1904. Emmons, S. F., Platinum in copper ores in Wyoming: U. S. Geol. Survey Bull. 213, pp. 94-97, 1903.

[5] Am. Jour. Sci., 4th ser., vol. 13, p. 95, 1902.

[6] Platinum and palladium in certain copper ores: Eng. and Min. Jour., vol. 79, pp. 985-986, 1905.

[7] Concentration of platiniferous copper ore at the Rambler mine, Wyoming: Met. and Chem. Eng., vol. 9, pp. 75-78, 1911. This article describes the methods of investigation and treatment, the experimental mill, giving its flow sheet and assays of the different table products and the assay methods employed.

was made,[1] but in 1912 the plant was shut down. An assay of a general sample on the stope level of the Rambler mine is reported to show 1.3 ounces of precious metals (mainly platinum and palladium) to the ton and 6 per cent of copper.[2] On account of the profound metamorphism of the Rambler deposit, due to oxidation and sulphide enrichment, the genesis of the deposit has not been satisfactorily established.

The platinum-bearing peridotite dikes near Bunkerville, Clark County, Nev., 25 miles east of Moapa and 100 miles northeast of the Boss mine, are described by Howland Bancroft.[3] The dikes, as determined on fairly fresh material from the Great Eastern prospect, consist chiefly of augite, olivine, biotite, and enstatite and contain pyrrhotite, probably nickeliferous, chalcopyrite, and magnetite. The sulphides are apparently of pyrogenic origin. A shipment of 91,600 pounds from the Key West dike showed a content of 2.3 per cent of copper, 1.79 per cent of nickel, and 0.13 ounce of platinum metals to the ton. As a result of careful experimentation Dickson [4] concluded that the platinum does not exist as sperrylite in this ore; it occurs apparently in a form soluble in nitric acid, caustic soda, or hydrofluoric acid.

A platiniferous deposit of contact-metamorphic origin in Sumatra is briefly described by L. Hundeshagen.[5] The deposit consists of wollastonite, garnet, and bornite and is regarded as having resulted from the metamorphism of a limestone lens by granite. Slightly decomposed wollastonite containing no copper proved to be richest in platinum, carrying 0.17 ounce to the ton, besides 0.11 ounce of gold.

A remarkable deposit of palladium-gold occurs at Candonga, in Minas Geraes, Brazil.[6] Gold and palladium-gold (an alloy of gold containing about 8 per cent of palladium) are found in a rock consisting of an intergrowth of pyroxene, actinolite, chondrodite, calcite, magnetite, and ilmenite. This lime-silicate rock was beyond question derived from a limestone lens in itabirite, as a result of the contact metamorphism produced by the intrusion of granitic and pegmatitic masses.

The Gongo Socco mine, also in Minas Geraes, produced 390,337 ounces of gold carrying approximately 4 per cent of palladium. This

[1] Horton, F. W., Platinum: Mineral Industry, 1911, p. 597, 1912.

[2] Met. and Chem. Eng., vol. 9, p. 76, 1911.

[3] Platinum in southeastern Nevada: U. S. Geol. Survey Bull. 430, pp. 192–199, 1910.

[4] Dickson, C. W., The distribution of the platinum metals in other sources than placers: Canadian Min. Inst. Jour., vol. 8, pp. 206–207, 1905.

[5] Inst. Min. and Met. Trans., vol. 13, pp. 550–552, 1905.

[6] Hussak, Eugen, Ueber das Vorkommen von Palladium und Platin in Brasilien: K. Akad. Wiss. Wien Sitzungsber., vol. 113, pt. 1. pp. 394–425, 1904. The main features of this report are summarized by its author in Zeitschr. prakt. Geologie, 1906, pp. 284–293.

deposit, like that of Candonga, is regarded by Hussak[1] as having originated as a result of the metamorphism exerted by granitic intrusions on a limestone layer in the itabirite series.

The Ruwe gold lode, in the Belgian Kongo, consists of a bed of sandstone in a series of sandstones and quartzites. It carries gold, platinum, palladium, and silver, said to average $17 to the ton. Gold and platinum are present in the metallic state, and with them are associated a number of lead and copper vanadates, together with pyromorphite and malachite. The origin of this deposit has not yet been established.[2]

The occurrence of platinum in quartz veins is recorded from a number of localities, but none of these appear to be of commercial importance. The platiniferous character of certain pyritic gold-quartz veins which traverse crystalline schists near the Rio Bruscus, in the State of Pernambuco, Brazil, has been demonstrated by Williamson.[3]

In New Zealand some small quartz veins cutting mica schists and phyllite have been found to be platiniferous by J. M. Bell;[4] the best, however, carries only 0.17 ounce of platinum to the ton. The associated sulphides are pyrite and chalcopyrite, and silver is present in the ratio of 7 parts of silver to 1 of platinum. The veins occur near altered magnesian plutonic rocks and are believed to have originated as a result of the intrusion of these rocks.

As early as 1806 Vauquelin had established the presence of platinum in the ore of a silver mine at Guadalcanal, Spain.[5] The mineral analyzed was tetrahedrite, or some mineral closely resembling it, and was found to contain copper, lead, antimony, iron, sulphur, silver, and some arsenic. The platinum content proved to be irregular, ranging from a trace to as much as 10 per cent. The veins are inclosed in mica schist and have a gangue of calcite, barite, and quartz.

Other examples of lodes in which platinum has been detected might be cited, but those already mentioned serve to illustrate the salient features of occurrences of platinum in veins. A. Eilers[6] has recently placed on record a table which gives the amount of platinum, palladium, and other elements contained in the blister copper from a number of the larger smelteries. Although these two metals are present in extremely minute proportions they are recovered during refining in the electrolytic muds, where they accumulate as valuable by-products. The palladium is generally more abundant

[1] Hussak, Eugen, Ueber das Vorkommen von Palladium und Platin in Brasilien: K. Akad. Wiss. Wien Sitzungsber., vol. 113, pt. 1, p. 391, 1904.

[2] Ball, S. H., and Shaler, M. K., Econ. Geology, vol. 9, pp. 633–635, 1914.

[3] Hussak, Eugen, Zeitschr. prakt. Geologie, 1906, p. 291.

[4] New Zealand Geol. Survey Bull. 1, new ser., pp. 50, 96, 1906.

[5] Kemp, J. F., The geological relations and distribution of platinum and associated metals: U. S. Geol. Survey Bull. 193, pp. 81–82, 1902.

[6] Occurrence of some of the rarer metals in blister copper: Am. Inst. Min. Eng. Bull. 78, pp. 999–1000, 1913.

than the platinum. The blister copper from the Steptoe smeltery, which treats the porphyry ore of Ely, Nev., contains 0.01 ounce of platinum and 0.044 ounce of palladium to the ton.

Of further interest in connection with the geology of platinum are the observations of Hussak [1] on the solution, migration, and redeposition of this metal by waters of surface origin. He believes that certain botryoidal, stalactitic nuggets of platinum were deposited from solutions that resulted from the oxidation of platiniferous sulphides or of sperrylite. The suggestion concerning the derivation of the metallic platinum from the oxidation of platiniferous sulphides is probably well founded, but that concerning the sperrylite seems not to be supported by the prevalence of this mineral in the gossan of the Vermilion mine in the Sudbury district.

CONCLUSIONS AND COMPARISON OF THE BOSS DEPOSIT WITH PREVIOUSLY KNOWN DEPOSITS.

The bedrock occurrences of platinum show that this element is concentrated mainly by magmatic processes, but these processes seem rarely or never to have gone far enough to produce deposits of economic value. As a rule, platinum is restricted to magnesian plutonic rocks, mainly dunites and allied varieties. It is present, however, as a minor constituent of some magmatic copper or copper-nickel ores, of which those of the Sudbury region are the most prominent examples; further, it occurs, as the table given by Eilers shows, in practically all types of copper ores, although in extremely minute quantities. This fact emphasizes the conclusion, first drawn by Kemp [2] after summarizing the information concerning the known distribution of platinum, that platinum "does appear sometimes in veins with other metals, especially with copper. It would follow that platinum migrates in solution." It is not improbable, therefore, that copper-bearing deposits may occasionally be found in which platinum forms an economically important constituent.

The association of platinum with siliceous igneous rocks is not wholly unknown. At Copper Mountain, British Columbia,[3] platinum occurs as sperrylite in a pegmatite dike which carries bornite, probably as a pyrogenic constituent. The pegmatite cuts gabbro, however, instead of granite, thus differing from normal pegmatites. In Sumatra a platiniferous deposit of contact-metamorphic origin has been recognized; it is thought to be genetically associated with granitic intrusions, but this relation has not been decisively established. In Brazil palladium-bearing gold deposits, also of contact-

[1] K. Akad. Wiss. Wien Sitzungsber., vol. 113, pt. 1, pp. 452, 458, 1904; see especially pl. 2, figs. 2 and 3.
[2] Kemp, J. F., U. S. Geol. Survey Bull. 193, p. 34, 1902.
[3] Catherinet, Jules, Copper Mountain, British Columbia: Eng. and Min. Jour., vol. 79, pp. 125-127, 1905.

metamorphic origin, are related to the intrusion of granite and pegmatite.

In short, then, primary deposits containing platinum in noteworthy quantities are mainly of igneous origin, but some of hydrothermal origin have been discovered and are mainly copper-bearing deposits. It is perhaps most reasonable to expect that platinum should occur, as a rule, in high-temperature copper veins—an expectation partly borne out by the Sumatran occurrence—but this supposition seems to be opposed by the fact that platinum in certain other recognized occurrences is associated with tetrahedrite, a mineral not characteristic of high-temperature zones.

From the foregoing discussion it is apparent that the gold-platinum-palladium deposit at the Boss mine is not closely similar to any other deposit carrying metals of the platinum group heretofore described. Its cupriferous character links it, however, with most of the other known platinum-bearing lode deposits. The occurrence of abundant gold together with palladium, on the other hand, is suggestive of the Brazilian deposits, as is also its probable genetic connection with siliceous igneous rocks.

NITRATE DEPOSITS IN SOUTHERN IDAHO AND EASTERN OREGON.

By G. R. Mansfield.

INTRODUCTION.

The nitrate deposits near Homedale, Idaho, appear to have been first discovered in the spring of 1914 by D. J. Sullivan, of Homedale, who, according to his own account, recognized their occurrence in the canyon of Jump Creek about 10 miles south of Homedale in proximity to an old metalliferous prospect just below the falls of that creek. Only a small quantity of the material was found, "enough to fill two flour sacks," but a strip of brown paper dipped in a solution of the substance and then dried and burned indicated by its sputtering scintillations the presence of a nitrate.

About the same time the young sons of George D. Huntley, whose ranch lies in the canyon of Sucker Creek about 10 miles west of the Jump Creek locality, were playing in a small cave at the base of a cliff in the canyon about half a mile below their home. Having started a fire in the cave, they were surprised to find that some of the white material at the back of the cave and in the crevices of the rock took fire and burned vigorously. This incident, together with the discovery by a camping party of a white deposit at several localities on Sucker Creek, was reported to Mr. Sullivan, who visited the place and again recognized the presence of a nitrate in the deposits. Meanwhile a prospector named Lacky who had passed through Sucker Canyon had collected a sample of the white material and had shown it to persons in Ontario, Oreg., among whom chanced to be Henry Wilson, a California mining engineer, who recognized the presence of a nitrate in the sample.

Mr. Sullivan and his associates staked out claims, and shortly afterward interested persons from Ontario made extended examination of the district and rapidly staked out a large area, so that considerable local excitement ensued. At the time of the writer's visit (November, 1914), however, no assessment work had been done except by Mr. Sullivan and his associates.

The writer wishes to express his appreciation of the kindness extended to him by Mr. Sullivan, who conducted him to the several

localities where the interesting deposits of the district could be best seen, and tendered him the hospitality of both camp and home. Thanks are due also to Messrs. F. E. and W. Tracy for courtesies in camp.

Mr. J. F. Hunter, jr., of the Geological Survey, has been kind enough to examine and discuss with the writer several thin sections of rocks from this region. The analyses of the samples were made in the laboratories of the Geological Survey by Mr. R. K. Bailey.

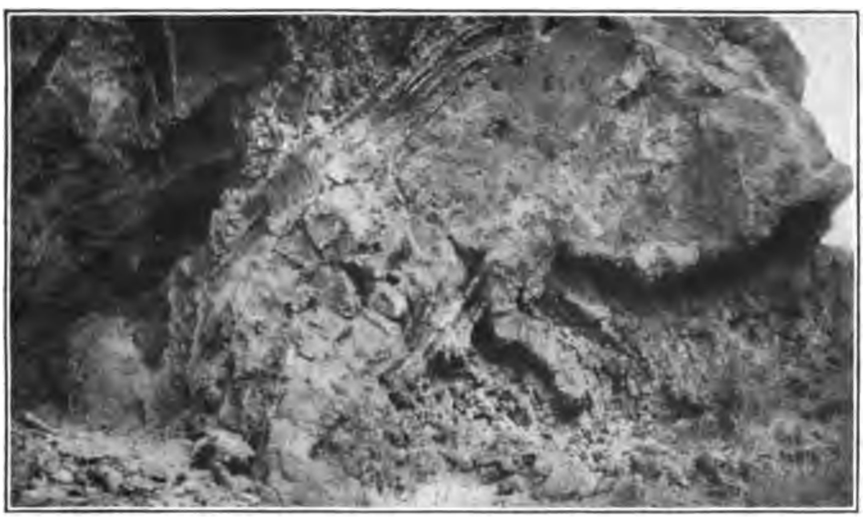
HOMEDALE DEPOSIT.

GENERAL FEATURES.

The Homedale nitrate deposit is located in and near the canyon of Sucker Creek, Oreg., about 16 miles in a direct line southwest of Homedale, Idaho (fig. 2), but the distance by the usual road is nearly 26 miles. With two exceptions the locations of claims and prospects on the map are approximate, because it proved to be impracticable to tie these locations to established land corners. The location of Huntley's ranch is taken from a legal description of the property placed in the writer's hands by Mr. Sullivan after the completion of the examination. The location of the American placer claim was fully set forth in the location notice at the discovery stake and prospect. The other location notices observed did not contain specific reference to established land lines. The Sucker Creek prospects are located with reference to Huntley's ranch and the Jump Creek prospects with respect to the topography shown on the map of the Silver City quadrangle published by the Geological Survey. Nitrate was originally discovered in this region in the canyon of Jump Creek about 10 miles south of Homedale, immediately below the falls in that canyon. The deposit in the Jump Creek locality, however, appears to have been exhausted with the first prospecting. In both localities the mode of occurrence of the nitrate is the same.

The rhyolite in which the canyons are cut forms vertical or overhanging cliffs. Along the bases of the cliffs there are local recesses or tiny caves. (See Pl. II.) Much of the rhyolite is close textured and massive, but there are zones where the rock is more open textured and shows pronounced banding and spherulitic structure together with some brecciation. Associated with these zones are certain bands, more massive than the others, that contain scattered vesicles, 2 to 6 inches in diameter, many of which are in part or wholly filled with opal, agate, or chalcedony. These vesicles give a blotchy appearance to the rock forming the cliffs. At these places also the rocks have a more or less shelly structure, so that fractures penetrate the rock in many directions and angular pieces 3 to 6 inches or more long and 1 to 3 inches thick are readily dislodged. (See Pls. II, III.)

A. CONTORTED FLOW STRUCTURE IN THE RHYOLITE ON THE WEST WALL OF SUCKER CANYON, OREG.



B. CONTORTED FLOW STRUCTURE IN THE RHYOLITE ON THE EAST WALL OF SUCKER CANYON, OREG.

PROSPECT AT THE ABBIE CLAIM ON HUNTLEY'S RANCH, OREG.

ABBIE CLAIM.

At the Abbie claim, on Huntley's ranch, this shelly zone is nearly 50 feet wide. The vesicles are partly filled with a green mineral,

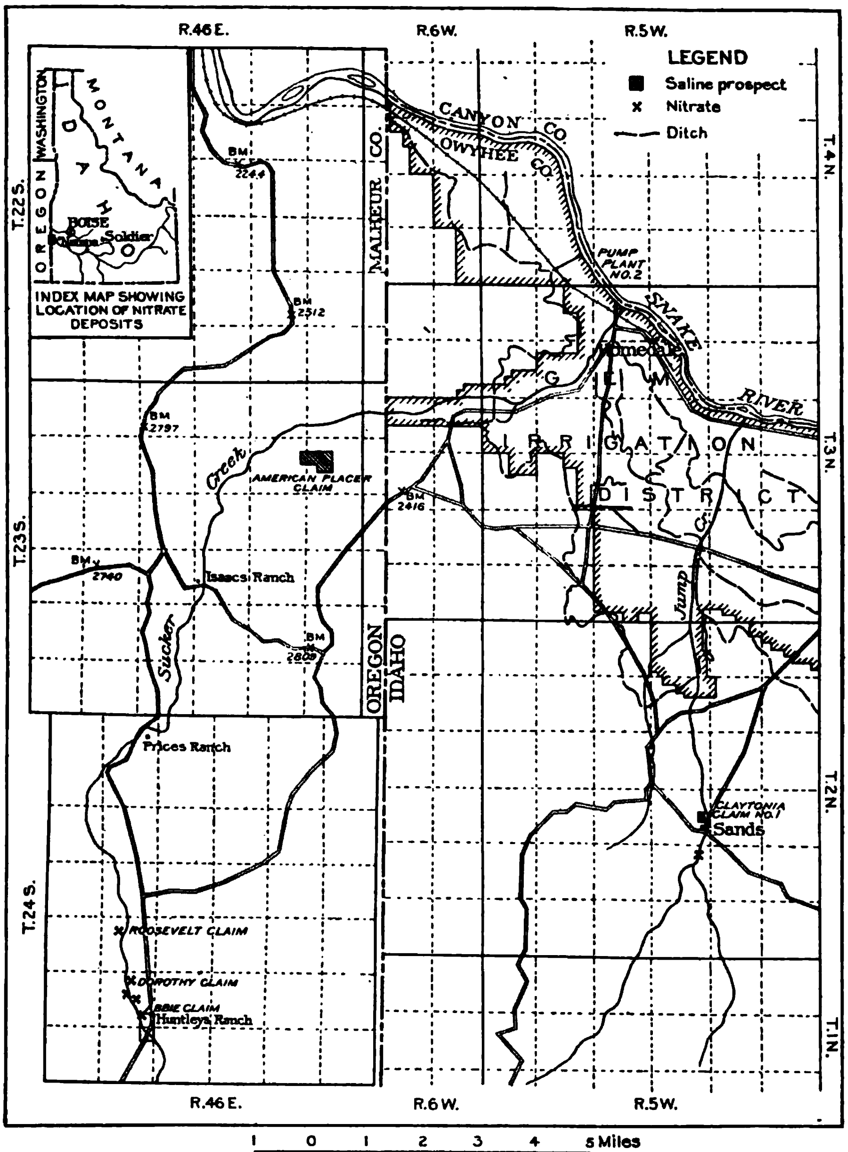


FIGURE 2.—General map of the nitrate field near Homedale, Idaho, with index map showing the location of the Homedale and Soldier deposits.

which is also disseminated to some extent through the rhyolite. In thin section, under the microscope, the rhyolite appears to be normal in composition, showing phenocrysts of quartz and feldspar having

maximum diameters of about 4 millimeters in a fine cryptocrystalline groundmass of quartz and orthoclase with a few specks of iron ore and a little chlorite. The green mineral is not differentiated by its refractive index from the surrounding rock and appears to be chalcedony. The color is apparently little more than stain, though fine particles of chlorite may be present.

In the cracks and crevices of the rock are veinlets of white, finely crystalline material which burns with a sparkling flame when a lighted match is applied to it and causes the glowing tip of the match to burn brightly at white heat. The veinlets are in general about one-eighth to three-eighths of an inch thick. When the fractured rock is picked away fresh seams or veinlets of the white deposit are exposed, but these, like the others, are only a fraction of an inch thick, and much of the deposit is so loosely aggregated that it crumbles and falls to the soil below when the shelly rock is disturbed. Samples of this material appear on analysis in the laboratories of the Geological Survey to consist essentially of potassium nitrate and sodium nitrate. (See p. 26.) Associated with the nitrate in the same or adjacent crevices is a somewhat harder and more firmly aggregated white mineral in fairly coarse fibrous or prismatic form. On analysis this material appears to consist essentially of the sulphates of sodium and magnesium. The zone in which these crevice deposits occur is not sharply defined but has a width of 3 or 4 feet. No distinct vein of the material is to be seen.

The nitrate tends also to accumulate in the border zone between the soil and the bases of the cliffs and can be exposed by scraping away the soil. It was reported that at the time of the discovery this material at the soil line was plentiful enough to be shoveled into buckets. This excess seems to have been removed, and only whitened soil and a scant white deposit are now found in this position. At this claim an opening about 10 feet long, penetrating the cliff face about 4 feet and extending along the nitrate-bearing zone for about 8 feet, had been made at the time of the writer's visit.

DOROTHY CLAIM.

At the Dorothy claim, situated about half a mile north of Huntley's ranch, at the base of the cliff on the east side of Sucker Creek, a pit about 8 feet long, 7 feet deep, and 3 feet wide has been opened. The face of the recess or cave has also been picked down a few inches or perhaps a foot. This is the locality at which the Huntley children discovered the inflammable nature of the deposit. The material at this claim is similar in nature and mode of occurrence to that of the Abbie claim. The width of the zone in which the veinlets occur is indeterminate but does not seem to exceed 3 feet. The veinlets themselves range from one-sixth to three-eighths of an inch in thick-

ness and occur in crevices between the rhyolite blocks. The sodium and magnesium sulphates in their coarse fibrous form occur in the same veinlets with the nitrate, which is here sodium nitrate, and in adjacent veinlets. The material at the soil line, which was reported to have been fairly abundant, has been largely removed, so that, as in the Abbie claim, only a whitened soil and a scant white deposit were to be seen in that position at the time of the writer's examination.

About 300 feet north of the Dorothy claim on the west wall of the canyon there is a white incrustation of small extent on the face of the cliff. This material has a sharp, puckery taste, resembling that of alum. A qualitative test shows it to consist essentially of the sulphates of alumina and magnesia. Some potassium is indicated in the analysis, but although a little of the potash alum may be present the composition of the substance is nearer that of pickeringite, the formula of which is $MgSO_4.Al_2(SO_4)_3.22H_2O$.

OTHER PROSPECTS.

Several prospects and numerous unprospected claims lie along Sucker Creek as well as east and west of the creek north of Huntley's ranch. The mode of occurrence and character of the deposits on these claims were similar to those above described. Samples were collected from only one, the Roosevelt claim, about 1½ miles below Huntley's ranch. Here only a small beginning at prospecting had been made, and the evidences of nitrate deposits were not as abundant as at the Abbie and Dorothy claims. Both the loosely aggregated nitrate and the more firmly aggregated fibrous mineral were present, however, and samples of each were collected for analysis. The samples were taken from the line of contact of the soil with the base of the cliff, by scraping away the soil. The nitrate deposit on qualitative analysis proves to be somewhat less pure than those already described, consisting of some potassium nitrate with admixtures of magnesium and sodium sulphates. The accompanying fibrous mineral, which showed no reaction with the match flame, contains magnesium sulphate, sodium chloride (common salt), and sodium nitrate.

At the same locality there was in places a pronounced red incrustation on the rock that had a pungent taste. A sample of this substance was collected and submitted to qualitative analysis. The soluble portion was found to consist essentially of sodium chloride and potassium nitrate, with some calcium nitrate and sodium sulphate. The insoluble portion of the coating was found to consist essentially of iron oxide (Fe_2O_3) with small amounts of the carbonates of calcium and magnesium.

Perhaps half a mile below the Roosevelt claim cracks in the face of the cliff contain common salt in somewhat greater abundance than at the localities previously noted. This spot has been discovered by cattle and horses that range in the vicinity of the canyon, as shown by the accumulation of manure at that place.

About 3½ miles below Huntley's ranch, at the foot of the canyon wall, on the east side of the canyon, there is a small spring. The temperature of the spring appears to be only slightly if at all above normal. The waters that supply the spring and seep from neighboring cracks are sufficiently charged with soluble salts to produce by evaporation a thin incrustation upon the adjacent rocks and also on bowlders in the bed of Sucker Creek for a short distance above and below the spring. The water, though slightly saline, is not unpleasant to the taste and in moderate amounts at least appears to produce no unpleasant effects after drinking. A small sample of the contained salts was obtained by scraping away with a knife some of the incrustation in the immediate vicinity of the spring. This powdery white substance fluxed readily in the match flame, but gave no suggestion of the presence of a nitrate. On qualitative analysis it proved to consist essentially of sodium sulphate with some magnesium sulphate.

The conditions in the canyon of Jump Creek, 10 miles east of Sucker Creek, are similar in the main to those along Sucker Creek. The walls of the canyon are formed of weathered and pinnacled rhyolite with cavernous recesses at the bases of the cliffs. Large bowlders and irregular masses of rock, which have fallen from the surrounding cliffs, obstruct the canyon and add to its wildness and picturesque appearance. Zones of shelly rhyolite with coarse scattered vesicles occur here, as on Sucker Creek. The caverns show a white incrustation, and many of the crevices have a white filling which melts but does not burn or sputter in the match flame. A sample of this salt gathered from a 2-inch zone along the soil line at the base of a little cavern in a large loose piece of rhyolite about a quarter of a mile below the falls proved on analysis to consist essentially of magnesium and sodium sulphates with some sodium chloride.

Just below the falls there is a ferruginous zone 2 to 3 feet wide along which and to the north of which the rock is much fractured. A short opening has been made in this ferruginous zone, and on the west, where the rock is more solid, an old tunnel has been driven in that direction some 60 feet. Just above this ferruginous prospect and in the fractured rock there is a little recess that has been deepened by picking. This is the place in which Mr. Sullivan made the first nitrate discovery in the district. The nitrate material seems to have been entirely exhausted, but the crevices contain a white,

coarsely fibrous or prismatic crystalline salt in veinlets one-eighth to three-fourths of an inch wide, with a strong puckery taste, resembling that of alum. A qualitative test, however, fails to show the presence of any significant amount of potassium, while aluminum, magnesium, and sodium are present in abundance. The substance is essentially a combination of the sulphates of the three last-named elements.

ANALYSES.

In order to get general information about the character of the samples from the Homedale district, a series of qualitative tests was first made. On the evidence afforded by these tests a selection was made of two samples of the nitrate which were regarded as representative of the group, and these were subjected to quantitative analysis. The results of some of the qualitative analyses have been mentioned above, but all these analyses are given on page 26 in tabular form for comparison and convenience of reference.

Qualitative analyses of samples from the Homedale district, Oregon and Idaho.

Field No. of specimen.	Locality.	Cl.	SO_4.	CO_3.	NO_3.	K.	Na.	Ca.	Al.	Mg.	Essential composition.	Remarks.
	OREGON.											
S. C. 1	Spring 3½ miles below Huntley's ranch.	None	Much	Small amount.	None	None	Much	Very little.		Fair	Na_2SO_4 with some $MgSO_4$.	Salt incrustation around spring.
S. C. 3	Dorothy claim	do	do	do	Good test.	None or trace.	do	Very small.		Much	$NaNO_3$ and Na_2SO_4	Discovery Cave on Sucker Creek.
S. C. 4	Abbie claim	do	Some	None	do	Much	do			Trace	KNO_3 and Na_2SO_4	
S. C. 5	About 300 feet north of Dorothy claim, on west wall of canyon.	do	Much	do	None	Some	do		Much	Much	Sulphates of aluminum and magnesium.	Incrustation supposed to be alum, but more closely allied to pickeringite $MgSO_4.Al_2(SO_4)_3.22H_2O$.
S. C. 6	Roosevelt claim	Small amount.	Some	do	Much	Small amount.	do	Some		do	$NaNO_3$, $Mg(NO_3)_2$, and $Ca(NO_3)_2$.	Better-grade material from prospect.
S. C. 7	do	Much	Small amount.	do	do	None	do	None		Some	$MgSO_4$, NaCl, and $NaNO_3$.	Fibrous mineral accompanying better nitrate.
S. C. 7a	do	do	Some	do	do	Some	do	Fair		Small	NaCl, KNO_3, some $Ca(NO_3)_2$, and Na_2SO_4.	Red incrustation, soluble part. Insoluble red material essentially Fe_2O_3 with possibly $CaCO_3$ and $MgCO_3$.
S. C. 8a	American placer claim.	None	Much	do	None	None	do	Small amount.		Very small.	Na_2SO_4 with some $MgSO_4$.	White efflorescent material near surface.
S. C. 8b	do	Small amount.	do	do	do	Some	do	do		Large amount.	$MgSO_4$, Na_2SO_4, and some NaCl.	Coarse crystalline deposit 2½ to 3 feet below surface and impregnated with clay.
	IDAHO.											
S. C. 9	Claytonia claim No. 1.	Some	do	do	do	do	do	do		do	$MgSO_4$, Na_2SO_4, and NaCl.	Coarse crystalline deposit, 10 inches more or less.
S. C. 9a	do	do	do	do	do	None	do	do		Much	$MgSO_4$ and Na_2SO_4	4 inches of yellow sand below S. C. 9.
S. C. 9b	do	do	do	do	do		do			do	NaCl, $MgSO_4$, and Na_2SO_4.	Gray sand below S. C. 9a, 18 inches.
S. C. 10	Jump Creek nitrate prospect.	None	do	do	do	None or trace.	do	None	Much	do	$Al_2(SO_4)_3$, $MgSO_4$, and Na_2SO_4.	Coarsely fibrous mineral in veinlets $\frac{1}{16}$ to $\frac{1}{8}$ inch wide.
S. C. 11	Jump Creek about one-fourth mile north of nitrate prospect.	Good test.	do	do	do	Trace or none.	do	do		do	$MgSO_4$ and Na_2SO_4	Incrustation on walls of tiny cave in large loose rock.

Complete quantitative analyses were made of two of the samples, Nos. S. C. 3 and S. C. 4, and a determination of the nitric acid in sample S. C. 6 was made. The results of these analyses are given in the following table:

Analyses of samples of nitrates from Sucker Creek, secs. 20 and 29, T. 24 S., R. 46 E., Willamette meridian, Oreg.

[R. K. Bailey, analyst.]

	S. C. 3 (Dorothy claim).	S. C. 4 (Abbie claim).	S. C. 6 (Roosevelt claim).
Cl	0.09	0.18	
SO_4	19.39	4.62	
HCO_3	None.	None.	
CO_3	None.	None.	
BO_3	None.	None.	
NO_3	47.25	59.91	73.75
Na	31.13	13.74	
K	.39	19.75	
Mg	.14	.03	
Ca	1.61	1.77	
	100.00	100.00	
Soluble portion (per cent of dry sample)	90.50	98.06	

On the assumption that the NO_3 in sample S. C. 3 is practically all combined with the Na, it is computed that the soluble portion of the dry sample contains 64.7 per cent $NaNO_3$ (sodium nitrate), equivalent to 58.5 per cent sodium nitrate in the entire sample.

On the assumption that all the NO_3 in sample S. C. 4 is combined with the K or Na, although a small amount may be combined with the Ca, it is computed that the soluble portion of the dry sample contains 50 per cent KNO_3 (potassium nitrate) and 40.6 per cent $NaNO_3$ (sodium nitrate), or 90.6 per cent total nitrates, equivalent to 88.8 per cent of the entire sample.

In sample S. C. 6 the other constituents besides the NO_3 were not determined, but from the combining weights of the elements concerned and the qualitative analysis given on page 26 it is assumed that the nitrates are in the form of sodium nitrate with probably magnesium or calcium nitrates and little if any potassium nitrate. The total nitrates probably exceed 90 per cent.

Samples S. C. 4 and S. C. 6 compare favorably with the best grades of nitrate reported from various western sources. They represent, however, selected material from their respective localities. Sample S. C. 3 is more nearly representative of the character of the deposit as a whole, because it contains a higher percentage of the sulphates which are present in each of the localities examined. In any attempt to work the deposit on a commercial scale it would be difficult if not impracticable to separate the nitrates from the sulphates that occur in the same and adjacent veinlets, so that it is probable that an average lot of the material from the entire Homedale district would not run higher than the 58.8 per cent sodium

nitrate of the dry sample S. C. 3 and it might even run lower. This figure, however, is higher than that for the better grades of saltpeter mined in Chile. (See p. 40.)

SOLDIER DEPOSIT.

MODE OF OCCURRENCE.

A number of samples of nitrate salts with accompanying pieces of country rock from a locality described as 9 miles east of Soldier, Idaho, and 9 miles north of the railroad, have recently been sent to the Geological Survey by Mr. John Finch. Soldier is in Blaine County, in T. 1 N., R. 14 E. Boise meridian. (See fig. 2, index map.)

The country rock is a rhyolite, which in thin section under the microscope appears much like the rhyolite at Homedale, except that it is somewhat more glassy and badly weathered. The rhyolite specimens show the same tendency to spherulitic texture and shelly structure that is possessed by the Homedale rock. The nitrate salts occur in depressions or small cavities in the rhyolite, and also impregnate the soil in certain places, probably at the bases of cliffs, as at Homedale. No examination of this locality has yet been made by the Geological Survey, but a study of the samples suggests that the mode of occurrence of the nitrate near Soldier is similar to that near Homedale. According to Mr. Finch there is a considerable quantity of the material readily accessible.

ANALYSES.

The samples from Soldier had broken loose in the sack in transit and had mingled to a certain extent. Four lots were selected, however, for qualitative analysis, and the results of the analyses are given in the following table:

Qualitative analyses of specimens of niter from a locality near Soldier, Idaho.

No.	Cl.	SO_4.	CO_3.	NO_3.	K.	Na.	Ca.	Mg.	Essential composition.
1...	Trace.	None.	None.	Much.	Much.	Fair..	Some.	Very little.....	KNO_3, some $NaNO_3$, and $Ca(NO_3)_2$.
2...	...do...	Some.	...do...	...do...	...do...	...do...	...do...	.....do........	KNO_3, with some $NaNO_3$ and $Ca(NO_3)_2$.
3...	None.	None.	...do...	...do...	...do...	Some.	....	....	KNO_3.
4...	Trace.	...do...	...do...	...do...	...do...	Fair..	Some.	Small amount	Same as Nos. 1 and 2.

1. Finer material, inclosed in paper sack, more or less distinct from the other samples.
2. Finer material, that came loose in large sack containing all the samples.
3. Filling dug out of cavity on side of large piece of rock.
4. Nitrate from a pocket on side of a large rock specimen.

The Soldier deposits, so far as represented by the samples examined, appear to be largely free from chlorides and sulphates, and to consist mainly of potassium nitrate, with less amounts of sodium and calcium nitrates. It was not deemed advisable to make expensive quantita-

tive determinations of the material submitted because of the condition of the samples and the lack of definite knowledge regarding their field relations.

EXTENT AND VOLUME OF THE NITRATES.

The Jump Creek deposit lies about 10 miles east of the Sucker Creek locality. According to Mr. Sullivan, indications of nitrate deposits occur between these two places, and have been found by others as far as 150 miles to the west of Sucker Creek, but the showing at Sucker Creek is better than that farther west. Soldier, Idaho, is about 120 miles east of the Sucker Creek locality. The occurrences of the nitrates above mentioned are all associated with rhyolites. Nitrate deposits in rhyolites occur at several places in Nevada and Utah.[1] The rhyolites seem to be widely distributed and to carry niter in many places, though niter is by no means confined to rhyolitic rocks. The Homedale district is therefore probably only a part of a much larger niter-bearing area, in which locally, as at Sucker Creek, the niter occurs in notable amounts.

The mode of occurrence of the nitrate in the Homedale district is described on pages 20–25. The little veinlets that contain the nitrate form only a small part of the whole mass in the zones where the nitrates occur—probably not more than 1 per cent—and the same veinlets carry other substances than nitrates, as is shown by the analyses. When the rock fragments are picked down from the cliff face at any of the prospects described, fresh veinlets are exposed, similar in character, number, and thickness to those previously found. How far into the rock this condition continues it is impossible to say from present data, as none of the prospects have penetrated more than 3 or 4 feet from the cliff face. The present evidence does not preclude the possibility of finding an increase in the size and number of the nitrate-bearing veinlets, or perhaps even large veins, when the rock is opened further. There seems, however, little likelihood of any marked increase in richness within the interior of the rock mass. On the contrary, it appears more probable that the richest parts of the deposit are those already exposed in the faces and along the bases of the cliffs and that the material will be found to grow gradually leaner and perhaps to disappear altogether as the rock is penetrated. Whatever may have been the mode of origin of the material, it probably owes its present position to the action of percolating waters on the one hand and to evaporation on the other. On that supposition the concentration of the deposit would naturally be greatest at or near the surface, where evaporation takes place. However, no positive statement can be made until more work has been done in opening the veinlet-bearing zones, both laterally and vertically.

[1] Gale, H. S., Nitrate deposits: U. S. Geol. Survey Bull. 523, pp. 16-25, 1912.

OTHER SALTS OF THE HOMEDALE DISTRICT.

DISTRIBUTION AND GEOLOGIC RELATIONS.

In secs. 11 and 12, T. 23 S., R. 46 E. of the Willamette meridian, Oregon (see fig. 2), east of Sucker Creek, there is a group of low rounded hills, some of which are bare of vegetation and are covered with dried clay comminuted into tiny angular fragments that are easily scraped aside by the foot. From 4 to 6 inches below the surface there is a white salt that is efflorescent and dried in the upper 3 or 4 inches but damp and coarsely crystalline below and 2½ feet or more thick. This material is somewhat impregnated by clay and is exposed in a group of prospect pits which have been opened to a depth of 2 to 3 feet. The material exposed beneath the salt bed is a fine massive drab clay. A placer claim of 120 acres, called the American placer, has been located on these deposits by the American Fertilizer Co. Samples of the efflorescent salt and of the unmodified salt were collected for analysis.

On Jump Creek, west of the McCloud ranch, there is a series of three low, rounded barren knolls just outside of the canyon. These knolls have been taken up as saline deposits by D. J. Sullivan and others under the name Claytonia claims. Claytonia claim No. 1 was visited by the writer in company with Mr. Sullivan. Its location with reference to established land surveys was not known at the time of the visit, as it had not then been surveyed. Its approximate location is shown in figure 2. The saline deposit here is similar in character and mode of occurrence to the American placer, described above. At the Claytonia No. 1 there is a prospect about 8 feet long, 5 feet wide, and 4 feet deep at which the following section was measured:

Section at Claytonia No. 1 claim, Jump Creek, Idaho.

	Ft.	In.
Clay, drab, broken, gypsiferous		5
Salt deposit, damp, sugary, coarsely crystalline, white and efflorescent in upper 2 or 3 inches		10±
Sand, yellow, fine, saline, gypsiferous		4
Sand, gray, fine, powdery, with ferruginous streaks near base, gypsiferous	1	6
Gypsum seam		2
Clay, gray, compact, gypsiferous to bottom of cut	1	6
	4	9

Samples of the salt and the two sandy zones beneath were taken for analysis. According to Mr. Sullivan, these deposits continue more or less intermittently outside the hills and up Sucker Creek as far as Huntley's ranch.

As mapped by Drake,[1] the above-mentioned deposits fall in the group of later lake beds—the Idaho formation, of Pliocene age—that occupies the Snake River valley and regions east of the Owyhee Range up to elevations of 3,000 feet. The Idaho formation is described in general terms as less indurated than the Payette formation (earlier lake beds), and as consisting of very soft, brilliantly white sandstones, changing in places to compact gypsiferous clay. In a few places gravel and fluviatile sand are also present. The following section is given for a point in a bluff not far from the Claytonia claims:

Section of bluff 3 miles west of Snake River, north of Squaw Creek, Idaho.

	Feet.
At top, sand and gravel, probably Pleistocene, resting on the lake beds	14
Exceedingly well and evenly stratified light-gray to buff clay, in thin beds and interbedded with many thin streaks of gypsum and gypsiferous sand	190

At the American placer the saline deposits seem to follow the contour of the hill. No bedding other than the line between the salt deposit and the underlying clay was observed in the prospects examined. The impression gained here was that the deposit was of secondary character, formed by capillary activity of impregnated waters and evaporation. At the Claytonia No. 1 claim bedded sands and clays were observed beneath the saline deposit. Though the surface appearance and the character of the two deposits are much alike, the bedding relations, so far as observed, suggest that the Claytonia deposit may be primary, having been originally deposited with the other sediments. A more extended examination of the region is needed before a final decision as to the primary or secondary nature of the deposits can be made.

ANALYSES.

Qualitative analyses of the five samples collected from the two localities were made, and are given on page 26 under the numbers S. C. 8a, 8b, 9, 9a, and 9b. The deposits appear to consist essentially of sodium and magnesium sulphates, with more or less sodium chloride—in other words, of a mixture of Glauber's and Epsom salts with common salt. The fact that practically all the deposit effloresces to a white powder on exposure to the drying action of the air indicates that little if any of the material is in the form of the mineral blœdite, a hydrous sulphate of sodium and magnesium, for this mineral does not alter on exposure to the air like the crystals of hydrous sodium sulphate. It was not deemed advisable at this time to incur the expense of quantitative determinations of the samples.

[1] Lindgren, Waldemar, and Drake, N. F., U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 104), 1904.

UTILIZATION OF THE NITRATES.

It has been pointed out in connection with the Homedale deposit that the veinlets which contain the niter and associated salts form a very small percentage of the rock mass in the niter-bearing zones. If it were practicable to leach the rock and remove the soluble salts without handling the rock itself, something might be done commercially with the niter. From the constitution of the country rock, however, it seems that little could be done without moving a relatively large amount of the rock. The cost of these operations and the necessary equipment, together with the uncertainty regarding the continuation of the deposits within the rock mass, would seem to allow little hope of successful commercial development.

The Homedale and Soldier deposits may be taken as types of material from localities in many parts of the country, ranging all the way from Oregon to Texas, from which specimens have lately been received by the Geological Survey. The niter occurs on the surface and in cracks, forming in places rich veins in considerable quantity, but at no place yet examined has this superficial material seemed to lead to deposits extensive enough to have commercial value. Investigations should be continued in the hope that a commercially valuable deposit may be found. At the present time, however, the outlook is not very promising.

UTILIZATION OF THE SULPHATES.

An account of certain deposits of sodium sulphate and the market conditions affecting them has recently been given by Gale.[1] There is at present no considerable market for sodium sulphate, or what is known in trade as "salt cake," which is the product of the first step in the Le Blanc process for the manufacture of sodium carbonate from sodium chloride. In this process salt cake is produced by the decomposition of sodium chloride with sulphuric acid, hydrochloric acid being a valuable by-product. At present, however, the Le Blanc process has been almost entirely displaced by the ammonia process for the manufacture of soda, at least in the United States. Glauber's salt[2] ($Na_2SO_4.10H_2O$) is manufactured for a few purposes, chiefly for medicinal use and for freezing mixtures. A considerable quantity is obtained from the residuals of the Stassfurt salts. In the manufacture of practically all qualities of glass, except lead glass, salt cake is superior to soda ash because it is cheaper per unit of alkali and because, owing to the higher temperature at which the glass furnaces work when using salt cake, a higher percentage of silica can

[1] Gale, H. S., Sodium sulphate in the Carrizo Plain, San Luis Obispo County, Cal.: U. S. Geol. Survey Bull. 540, pp. 428-433, 1914.

[2] Thorpe, E., Dictionary of applied chemistry, vol. 5, pp. 21, 27, 581, 1913.

be used, thus again cheapening the cost and also producing a harder and more durable glass. Sodium sulphate is also used in the manufacture of ultramarine, which in turn has a wide use in a variety of manufactures because of its brilliancy as a body color and its high coloring power. Sodium sulphate is also used in the general processes of dyeing and coloring. Quotations on sodium sulphate in current trade journals range from 55 to 65 cents per 100 pounds for glassmaker's salt cake and 60 to 75 cents per 100 pounds for Glauber's salt in barrels. This is equivalent to $11 to $15 a short ton.

Magnesium sulphate is the purgative principle of many bitter spring waters and, as Epsom salts, has a considerable use in medicine. It is also used in warp sizing and weighting in cotton mills. The magnesium sulphate of commerce is derived chiefly from the kieserite ($MgSO_4+H_2O$) of Stassfurt. It is also manufactured to some extent in the United States from magnesite and dolomite. There is at present no large market for magnesium sulphate. Quotations on Epsom salts in current trade journals range from 1 to 1½ cents a pound in bags or barrels. This is equivalent to $20 to $30 a short ton.

In view of the present moderate or slight demand for the sulphates of sodium and magnesium and the fact that this demand is largely met in by-products derived from the manufacture of soda and potash salts, there seems little likelihood of the development on a commercial scale of mixed deposits such as those near Homedale unless they should prove to be present in much greater abundance than now seems probable. There is probably not enough sodium chloride in the deposits to warrant their development as a source of common salt.

GEOGRAPHY AND GEOLOGY OF THE HOMEDALE REGION.

PREVIOUS WORK.

Land surveys of the entire district discussed in this report have been made, and plats of the several townships are on file in the General Land Office, Washington, D. C. A large part of this work is relatively recent, the dates of the surveys ranging from 1878 to 1914.

Much of the area has been included in topographic surveys by the Geological Survey and three maps, covering the Nampa and Silver City quadrangles, Idaho, and the Mitchell Butte quadrangle, Oreg., have been issued. The junction point of the three quadrangles lies in latitude 43° 30′ N., longitude 117° W., about 9 miles S. 25° W. of Homedale.

The entire district has been discussed by Russell [1] in earlier reports of the Geological Survey, but these were reconnaissance reports that covered a broad area, so that they furnish few details bearing directly on the nitrate district. The particular object of Russell's work was the investigation of ground-water conditions, but it throws considerable light on the general geology of the region as a whole.

Parts of the district and some adjacent regions have been made the subject of more detailed geologic surveys. The Nampa and Silver City folios of the Geologic Atlas [2] issued by the Survey contain many details relating to the geology of the eastern part of the area, and much of this information is directly applicable to the unmapped western part. Oil and gas investigations have also been undertaken by the Survey in regions adjacent to the nitrate district. [3]

GEOGRAPHY.

LOCATION AND ACCESSIBILITY.

Homedale lies in the northwestern part of Owyhee County, Idaho, on Snake River near the State line. A branch railroad connects it with Nyssa, Oreg., a junction point, 20 miles to the north, on the Oregon Short Line Railroad. Stage connections are maintained with Caldwell, Idaho, also on the Oregon Short Line Railroad, about 12 miles in a direct line N. 75° E. from Homedale. Although more or less mining has been done in the hills bordering the Snake River valley in this region, the interest of the valley towns, including Homedale, is chiefly agricultural, and water is available through several irrigation projects. Homedale lies in the Gem irrigation district. At the time of the writer's visit the town comprised about 280 voters, including both sexes.

George D. Huntley's ranch, near which the nitrate deposits of Sucker Creek were first found, is in the SE. ¼ SE. ¼ sec. 29 and the NE. ¼ NE. ¼ sec. 32, T. 24 S., R. 46 E. Willamette meridian, in Malheur County, Oreg. Huntley's ranch has recently been sold to D. J. Sullivan. This part of the district is not included in the quadrangles named above but lies 4 or 5 miles west of the Silver City quadrangle.

A preliminary railroad survey along Sucker Creek to the southwest and south from Homedale has already been made. In the event of the completion of this railroad the agricultural, grazing, and mineral lands of the district will be readily accessible from the main line to the north.

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[1] Russell, I. C., U. S. Geol. Survey Bull. 199, 217, 252; Water-Supply Paper 78.

[2] Lindgren, Waldemar, and Drake, N. F., U. S. Geol. Survey Geol. Atlas, Nampa folio (No. 103); Silver City folio (No. 104), 1904.

[3] Washburne, C. W., Gas and oil prospects near Vale, Oreg., and Payette, Idaho: U. S. Geol. Survey Bull. 431, pp. 26-57, 1911.

TOPOGRAPHY.

The hills south of Snake River in this district are the lower foothills of the north end of the Owyhee Range. The country here is essentially a submaturely dissected high plain that slopes gently northward and is underlain by lavas with associated tuffs and lake beds. Flat-topped strips of hills with intervening valleys extend generally north or northeast. Where the valleys are cut in tuffs or lake beds they broaden, but where they encounter massive sheets of lava they form sharp-featured canyons with precipitous or even overhanging walls 250 to 300 feet high. The highest land in the part of the district examined does not much exceed 4,700 feet, and the lowest elevation, where Snake River leaves the district, is a little less than 2,200 feet, so that the maximum relief is about 2,500 feet. Some of the deeper canyons not included in the district have walls that rise steeply from 1,000 to 1,800 feet in height.

In the immediate vicinity of Snake River and for 8 miles or more to the south the country is nearly flat. It has an elevation of 2,300 to 2,400 feet and rises gently to 2,500 feet at the base of the hills. Near the river the surface soil is sandy, but a mile or two back from the river the surface is covered with a fine-textured, compact whitish soil that in the roads is cut into a fine, impalpable dust 2 to 6 inches deep. When wet this dust is transformed into a sticky mud that cakes wheels and impedes travel.

DRAINAGE.

All the drainage of this district is tributary to Snake River, which flows through the northern part. The volume of the Snake varies with the season, being highest in June and lowest sometime in the winter or early in the spring. The flow probably ranges from about 8,000 second-feet at the low stage to about 40,000 second-feet at the high stage. The river at Homedale flows between bluffs about 30 feet high, at a grade of about 5 feet to the mile. The river here is probably still eroding its channel, for low-lying islands in the vicinity of Homedale are seldom flooded.

In the district under discussion only two minor streams need be mentioned. These are Sucker and Jump creeks. Sucker Creek rises well back in the range toward Silver City and flows 40 miles or more before joining the Snake. It is a permanent stream of small volume. Jump Creek is much shorter, and its waters generally sink in the plain before reaching Snake River.

CLIMATE.

This part of the Snake River valley lies in the arid belt, and its climate and vegetation are closely allied with those of the Great Basin. The Pacific meteorologic influences are strongly felt, so that

the climate is comparatively mild. The precipitation is somewhat greater than in the Great Basin. In the valleys the temperature may exceed 100° F. for a few days in summer; in winter it rarely sinks to 0° F., though an occasional cold wave may force the temperature considerably below zero for a short time. At Boise the mean annual temperature is 50° to 53° F. The winds are generally from the southwest, but are seldom very strong. They often carry much dust.

It is claimed by the residents of Homedale that they have the least rainfall in the State. The normal annual rainfall at Nampa is reported to be 10.06 inches. Most of this falls between September 1 and June 1 and is fairly well distributed through these months. In ordinary winters but little snow falls in the valleys, and this does not long remain on the ground. In the hills south of the district the rainfall is somewhat greater, and snow may linger in protected places far into the summer. Springs in the hills are numerous.

VEGETATION AND INDUSTRIES.

The vegetation is scanty and is mainly sagebrush. The soil is said to be highly productive when irrigated and to be adapted for the growth of fruits, vegetables, and grain. The hills support many sheep that in the winter are fed in the valley. It is stated that some 50,000 sheep are wintered in the valley in the vicinity of Homedale.

GEOLOGY.[1]

IGNEOUS ROCKS.

The rocks of the southern part of the district are massive rhyolites that form part of the great body of rhyolite which surrounds the central part of the Owyhee Mountains. The rhyolite was outpoured in viscous masses over uneven surfaces, so that its thickness varies, but in the region covered by this report it is about 1,500 feet thick. When fresh the rhyolite is characterized by rough plateaus bordered by abrupt and rocky bluffs, and the faces of many of the cliffs present a rough columnar structure. In the canyons curious spires and pinnacles are produced by differential weathering. Where the rhyolite is softened by alteration it forms sloping ridges.

The appearance of the rhyolite is similar to that seen in most of the areas of that rock found in the West. The rock in general is compact, hard, and very resistant to weathering. Its color is grayish, greenish, yellowish, or brownish in different shades, varying greatly and abruptly. Practically all the varieties belong to the structural group comprising felsophyric rhyolite. These rocks are rich in silica and alkalies.

[1] See U. S. Geol. Survey Geol. Atlas, Nampa folio (No. 103) and Silver City folio (No. 104), 1904.

The writer has examined several slides of the rhyolite from Sucker Creek in the vicinity of the nitrate deposits, including a green variety that first appears in the canyon about 3 miles north of Huntley's ranch. The slides all showed the rock to be rhyolite of the usual type. The rhyolite in Sucker Creek is marked at several localities by a strongly developed flow structure that is steeply inclined or nearly vertical, with brecciation and the development of folds. (See Pls. II, III.)

From their relations to the lake beds which are in part derived from them and overlie them the rhyolites are believed to be of Eocene age.

Other igneous rocks, both earlier and later, occur in the region to the south and southeast of this district, but they have little bearing on the subject of this report.

SEDIMENTARY ROCKS.

The sedimentary rocks of the district are Tertiary lake beds and Quaternary stream deposits. The lake beds form gently sloping plateaus of almost horizontally bedded sediments which by various features show that they were for the most part deposited in a large body of fresh water. The persistently fine-grained character of the sediments, the absence of cross-bedding, such as would indicate strong currents, and the common occurrence of gypsiferous sands are regarded as evidence of lacustrine origin. Fluviatile deposits were naturally formed in many places contemporaneously with the recession of the lakes, but these are of less extent. In some places later thin basalt flows are intercalated in the uppermost lake beds. The sediments are predominantly sandy materials, more or less consolidated, but also with subordinate amounts of clay and volcanic tuffs. Gritty sandstones, generally micaceous, are common. Conglomerates occur also but are rarely coarse. They consist chiefly of granite pebbles, but at some places rhyolitic and basaltic pebbles are found. Silicified wood and opalized wood are common. In many places the lake beds are of a dazzling white color, but the clays in some localities are decidedly yellow and in others brownish or greenish brown. The brownish clays are usually lignitic, and the greenish-brown clays and sands appear to be in part basaltic tuffs.

Near the point where the stage road from Caldwell to Jordan Valley crosses Sucker Creek, near the State line, at an elevation of 4,800 feet, an extensive flora was found in horizontal lake beds and proved to be identical with that of the Payette formation near Boise. The flora is referred by Knowlton to the upper Eocene. Occasionally mammalian remains are also found in the lake beds. A later group of lake beds in the Snake River valley, which show different petrographic characters and a later fauna, are referred to the Idaho formation, of Pliocene

age. These beds are not, however, easily differentiated in appearance from the older beds.

The lake beds are more or less dissected by Sucker Creek and other streams, but the interstream surfaces have not been generally lowered.

Quaternary deposits are present in the form of local stream fans that spread over the lake beds from both sides of the range in a thin sheet of angular gravel and in earlier and later terrace gravels along the Snake River valley, extending back toward the hills. These deposits merge into one another and are in many places not distinctly separable. Recent alluvium forms a narrow strip along the present valley bottom of the Snake.

STRUCTURE.

The rhyolites and lake beds dip away gently from the granitic core of the Owyhee Range, so that on the west side of the range, where the nitrate field lies, the dips are generally westward and the strike somewhat west of north. In some localities the beds are horizontal or only slightly inclined. The structure of the distorted beds of lava along Sucker Creek near Huntley's ranch is regarded as a feature of the original outpouring of the viscous lava rather than a result of subsequent deformation. (See Pl. II.)

There appears to be some evidence of faulting along Sucker Creek, however. About 3½ miles north of Huntley's ranch brown lake beds on the east side of the canyon lie opposite purplish rhyolite on the west side and purplish-gray rhyolite on the east side lies opposite green rhyolite on the west side, while small masses of green rock still cling to the vertical or overhanging wall on the east side. The green rhyolite is in part tuffaceous and bears evidence of some hydrothermal action.

GEOLOGIC HISTORY.

According to Lindgren and Drake[1] an early Tertiary epoch of erosion was followed by outbursts of rhyolite and basalt and the deposition of the lake beds composing the Payette formation, which near the margins of the basin had a probable thickness of about 2,000 feet. The Payette formation is probably of Eocene age. The deposition of the Payette beds was followed by an apparently short and active epoch of erosion during which the rivers cut down through the lake beds to the same depth that they have to-day. Causes not yet known checked this erosion and produced a lake of smaller dimensions and shallower depth than the Payette lake. In this the beds of the Idaho formation with their Pliocene fauna were deposited.

[1] U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 104), 1904.

The draining of this lake is considered to have closed the Tertiary period. Since then the region has been dry land, and slow, frequently checked erosion has cut into the lake beds and deposited the material in extensive areas of Quaternary sand and gravel.

NITRATE DEPOSITS IN GENERAL.

The subject of nitrates with special reference to deposits in the United States has been reviewed by H. S. Gale.[1] Nitrate salts are widely distributed in several forms. They are found in all fertile soils in small amounts, and it has recently been argued that they occur in sedimentary rocks from which certain soils have been derived.[2] The nitrate salts thus distributed are not considered recoverable for commercial use except under some unusual condition. They are also found in more concentrated form in arid climates as in the well-known extensive deposit in Chile, the so-called "niter spots" of Colorado and Utah, and other scattered deposits in arid portions of the West. The general solubility of nitrate salts is so great that they do not accumulate in moist climates except in protected places such as caves and beneath overhanging cliffs. The nitrates are usually white crystalline salts with a pronounced taste, the character of which varies with the base with which the nitric acid is combined.

SODIUM AND POTASSIUM NITRATES.

COMPOSITION AND GENERAL PROPERTIES.

The nitrates most common in occurrence as well as most important in commerce are those of sodium and potassium.

Sodium nitrate, sometimes called soda niter, cubic niter, or Chile saltpeter, has the same crystalline form and cleavage as calcite—that is, it is rhombohedral. The angles of the rhombohedra are nearly right angles, whence the name cubic niter. The pure salt forms colorless, transparent crystals of the composition $NaNO_3$, in which nitrogen pentoxide constitutes 63.5 per cent and soda 36.5 per cent. Sodium nitrate deflagrates on charcoal and hence will flare when thrown upon burning coals, though less violently than potassium nitrate. The sodium combined in it imparts a strong yellow color to the flame. Sodium nitrate is deliquescent and very soluble in water. Its solubility increases with increase of temperature, 100 parts of water dissolving about 70 parts at 0° C., about 80 parts at 15°, and 125 parts at 68°.

[1] Gale, H. S., Nitrate deposits: U. S. Geol. Survey Bull. 523, 1912.

[2] Stewart, R., and Petersen, W., The nitric nitrogen content of the country rock: Utah Agr. Coll. Exper. Sta. Bull. 134, 1914.

Potassium nitrate, also called niter or saltpeter, in crystalline form is orthorhombic. Its composition is KNO_3, in which nitrogen pentoxide constitutes 53.5 per cent and potash 46.5 per cent. Potassium nitrate occurs naturally as thin white granular crusts or masses or in minute needle-form crystals, and as a thin coating on earth, walls, and rocks. The pure salt is transparent and crystalline and has a cooling, rather sharp saline taste. It deflagrates strongly when thrown on burning coals. The potassium combined in it imparts a strong violet color to the flame. In impure material this color is often masked by the yellow of sodium, but the violet color of potassium may be recognized if the flame is viewed through blue glass, which shuts out the yellow color. The salt dissolves readily in water and is not altered by exposure.

A piece of hot charcoal or the glowing tip of a burnt match will glow at white heat in contact with sodium or potassium nitrate, and the nitrate will tend to fuse and burn with a sputtering flame. Also a piece of paper moistened in a solution of one of these nitrates and then dried will burn with a sputtering flame.

CHILEAN DEPOSITS.

The nitrate deposits in the deserts of Atacama and Tarapaca, Chile, occur in beds having a maximum thickness of about 6 feet. They usually occur near the surface but in places lie beneath an overburden of 30 feet. The nitrates are never pure but are mixed with sodium chloride and other salts and impregnated with insoluble earthy matter. The crude mixture may contain as much as 60 or 70 per cent of sodium nitrate, but 50 per cent material is considered high grade. Material containing less than 10 per cent is too poor to be mined at a profit now.[1] Much has been written about the Chilean deposits, but further reference to them can not be made here. A partial bibliography of them is included in Bulletin 523.

USES OF SODIUM AND POTASSIUM NITRATES.

Sodium nitrate is used for many of the purposes for which the potassium salt is employed, but its hygroscopic nature makes it unavailable for the manufacture of gunpowder or fireworks. For making nitric acid, for supplying that acid in sulphuric-acid manufacture, and for use as a fertilizer it has entirely replaced potassium nitrate. It is also the principal source of the potassium salt, which is obtained from it by double decomposition with the potassium chloride of Stassfurt.

Potassium nitrate (niter or saltpeter) is used chiefly in the manufacture of gunpowder or other explosives but also in fireworks, in

[1] Ross, W. H., The origin of nitrate deposits: Pop. Sci. Monthly, August, 1914, pp. 134-145.

lucifer matches, for curing meat, for the manufacture of certain kinds of glass, for flux in metallurgic assays, for dyeing, and in medicine.

According to Pennock[1] 535,820 tons of sodium nitrate was imported into the United States in 1910 from Chile. This material was utilized in various industries, as follows:

Consumption of nitrate of soda from Chile in 1910.

	Per cent.	Tons.[a]
Explosives	41	219,686
Fertilizers	13	69,657
Dyestuffs	12	64,298
General chemicals	10	53,582
Nitric acid	9	48,224
Sulphuric acid	6	32,149
Glass	4	21,433
Unaccounted for	5	26,791
	100	535,820

[a] Computed from percentages given by Pennock.

PRICES OF NITRATES.

The total imports of nitrates by the United States in 1913 and 1914, together with the reported value, are given in the following table:

Imports of nitrates, 1913–14.[a]

	1913			1914		
	Quantity.	Value.	Value per ton.[b]	Quantity.	Value.	Value per ton.[b]
Nitrate of soda.........long tons..	625,862	$21,630,811	$34.56	543,715	$15,228,671	$28.01
Nitrate of potash (crude).pounds..	9,876,910	262,575	59.49	2,229,856	74,743	73.92

[a] Monthly Summary of Foreign Commerce of the United States, December, 1914.
[b] Computed from totals given.

According to recent statistics,[2] there has been for the last few years a marked increase both in the quantity and in the price of imported nitrates. During the year 1914, however, there was a noticeable reduction in the importations of both sodium and potassium nitrates. Sodium nitrate has fallen in price, but potassium nitrate has shown a marked increase. Doubtless these changes in the normal rate of advance are due to the disturbance in trade caused by the great European war.

ORIGIN OF THE HOMEDALE NITRATES.

A review of the hypotheses of the formation of nitrates, together with an account of the processes of nitrification, is given in Survey Bulletin 523. An interesting summary of the various modes of

[1] Pennock, J. D., Jour. Ind. and Eng. Chem., vol. 4, p. 173, 1912.
[2] U. S. Geol. Survey Mineral Resources for 1913, pt. 2, p. 105, 1914.

occurrence of nitrates and the many explanations of their origin is given in a recent paper by Ross.[1]

The most prevalent views of the origin of niter require the presence of organic matter in some form and the action of micro-organisms. In the descriptions of cave deposits given in Bulletin 523 it is shown for some deposits and assumed for others that bacterial activity upon organic matter in the form of animal excreta has caused the development of the nitrates.

The Homedale deposit and probably the Soldier deposit also belong to the general group classed as cave deposits. There is, however, little direct evidence of the former presence of animal excreta at the Homedale deposit. There may indeed be inconspicuous amounts of such material present in cracks or openings of the rocks above and more or less remote from the deposit. Bacterial action would develop nitrates from such material, and percolating waters penetrating the more shelly and fissured zones would carry these soluble salts to favorable places for their concentration by evaporation. Such places would be the faces of cliffs protected from rain or melting snow, the walls of shallow caves, and crevices leading to these places. In a similar manner organic matter disseminated through the soil above the cliffs might, through bacterial action, furnish nitrates which could be removed and concentrated as above outlined. It is probable that organic matter in one or both the forms mentioned has been the chief source of the nitrate deposits near Homedale and at Soldier. There are, however, other possible sources that deserve some discussion.

The occurrence of nitrates in association with igneous rocks at numerous places in the West has led many observers to the suggestion that the nitrogen of these deposits may have had a volcanic source. This idea was forcibly impressed on the writer by the sight of the disturbed structures in the rhyolite and the spherulitic, vesicular, and shelly zones in the rock in the immediate vicinity of the deposits near Homedale (Pls. II, III). The suggestion was strongly conveyed that the rhyolite at this place may have been near the site of a former vent or point of eruption and that volcanic emanations may have played some part in the supply of the nitrogen now forming the nitrates.

The presence of ammonium chloride in the fumaroles of a number of volcanoes, notably Vesuvius, has long been known. Nitrogen is also recognized among the gases that escape in volcanic eruptions. Considerable discussion, which has been well summarized by Clark,[2] has taken place with regard to the source of this nitrogen. The idea that the nitrogen originates from organic matter, such as vegetation, with which the lava comes into contact, or from the nitrogen of the

[1] Ross, W. H., The origin of nitrate deposits: Pop. Sci. Monthly, August, 1914, pp. 134-145.

[2] Clarke, F. W., The data of geochemistry, 2d ed.: U. S. Geol. Survey Bull. 491, pp. 248 et seq., 1911.

air does not seem well sustained. Although Lacroix [1] notes the production of ammonium chloride by one of the lava flows in covering cultivated or inhabited ground during the eruption of Vesuvius in April, 1906, many occurrences of ammonium chloride are such as to preclude the presence of organic matter. Although special instances like that cited by Lacroix may occur, the nitrogen of the lava at volcanic eruptions is regarded as clearly an original constituent and not of organic origin. It has been argued that nitrides within the earth may be the source of the nitrogen. Under the assumption that the nitrogen of the Homedale and other similar regions might have had a volcanic source, it might be supposed that ammonium chloride formerly present in the rocks had by bacterial or other agencies been changed into nitrates and localized by percolating waters and evaporation. At least two factors more or less unfavorable to this view may be cited. (1) The analyses of the nitrate samples from Homedale and Soldier show no trace of the presence of boron, which might perhaps be expected under the volcanic assumption, as the volcanic origin of many borate deposits seems fairly well established; (2) several changes of climate have undoubtedly occurred since the outpouring of the rhyolite, and it seems probable that during the moister climatic epochs much of the ammonium chloride and its derived salts would have been removed by leaching, although in this case much would depend on the manner of the original distribution of the ammonium chloride.

Another fact, which, so far as the writer is aware, has not been considered in this connection, should be mentioned. It has long been known that nearly if not quite all rocks, on heating to redness, give off large quantities of gas. This fact was noted by Priestly as early as 1781. It was at first thought that the gases were occluded in the rocks, but it has recently been shown that igneous action may generate them from the solid minerals themselves.[2] R. T. Chamberlin [3] cites many analyses of gases derived by heating powdered rock in a vacuum. Most of the common rock types were included in his experiments, and practically all the evolved gases were shown to contain nitrogen.

With regard to these gases the attention of investigators thus far has centered chiefly on their origin. The present evidence points strongly to nitrides as the source of at least a part of the nitrogen. Inasmuch as nitrogen is evolved from many kinds of rocks, as is shown by Chamberlin's analyses, it would seem that nitrides yet

[1] Lacroix, A., L'éruption du Vesuve en avril 1906; IIme partie, Les fumerolles et les produits de l'éruption: Rev. gén. sci., vol. 17, pp. 923-936, Nov. 15, 1906.

[2] Clarke, F. W., op. cit., pp. 261-265.

[3] The gases in rocks: Carnegie Inst. Washington Pub. 106, 1908.

unrecognized may be widely distributed through the rocks that make up the outer crust of the earth. The gases thus far examined have all been obtained at relatively high temperatures—360° to 850° C. In the presence of water vapor or hydrogen ammonia gas is developed from a nitride. It would be interesting to discover if possible whether similar gases are evolved from rocks in the slow processes of weathering and subaerial denudation and whether these conditions and the influence of bacteria might produce nitrates which would be carried in solution and concentrated at favorable places by evaporation.

GOLD DEPOSITS NEAR QUARTZSITE, ARIZONA.

By EDWARD L. JONES, Jr.

INTRODUCTION.

This report is based on information obtained by the writer in April and May, 1914, while he was classifying the lands in the Colorado River Indian Reservation. The area considered includes the southern part of the reservation and the region extending eastward from the reservation to the Plomosa Mountains. The geology and ore deposits within the reservation were more particularly studied, the time allotted to the examination being too short to permit detailed work in the area farther east. For information concerning placers outside the reservation the writer is indebted to Mr. E. L. Dufourcq, who conducted the testing of placer ground near Quartzsite. Mr. W. W. McCoy, of San Bernardino, kindly furnished the early history of the La Paz district, and Mr. Edward Beggs, of Quartzsite, gave much useful information regarding the La Paz placers. In 1909 Howland Bancroft[1] made a geologic reconnaissance of northern Yuma County and much of the country around Quartzsite and farther west to the reservation line. In his report he mentions the La Paz district and briefly describes placers in the Plomosa Mountains and prospects on gold-bearing quartz veins in the vicinity of Quartzsite.

The map that accompanies the present report (Pl. IV) is compiled from the records of the General Land Office. The area within the reservation has been subdivided into sections; the land east of the reservation is unsurveyed. The mountainous areas in the reservation are indicated on this map by patterns showing the geologic rock formations; the mountains in the unsurveyed area are represented approximately by hachures.

GEOGRAPHY.

The topography of southwestern Arizona is characterized by small detached, generally northward-trending mountain ranges separated by broad aggraded desert plains. Quartzsite lies in the broad basin

[1] Bancroft, Howland, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: U. S. Geol. Survey Bull. 451, 1911.

of Tyson Wash at the northern end of La Posa plain, in southwestern Arizona, between the Plomosa Mountains on the east and the Dome Rock Mountains on the west, at an elevation of about 850 feet. The distance between the Plomosa and Dome Rock mountains at the narrowest part of the plain is probably not less than 6 miles. Quartzsite is in the west-central part of Yuma County and is best reached by a daily automobile stage line, 25 miles long, from Bouse, Ariz., a station on the Arizona & California branch of the Atchison, Topeka & Santa Fe Railway. A road leading westward from Quartzsite traverses the southern end of the reservation and one leading southward traverses the broad stretch of desert to Yuma.

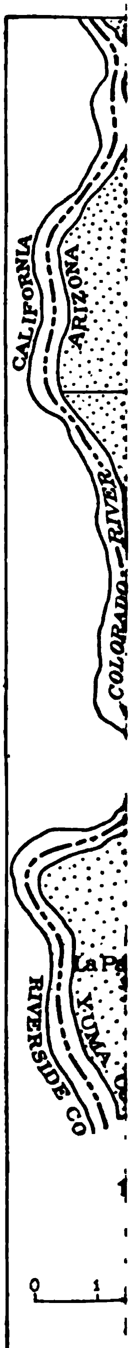
Most of the mountains in this region attain elevations not exceeding 2,000 feet above the surrounding desert. Ferrar Peak, 2,900 feet high, is the highest elevation near Quartzsite. The two small outlying ridges north of Tyson Wash rise not more than 800 feet above the surrounding bench lands, but the average relief is less than 500 feet. Gravel and wash covered bench lands slope gently westward from the Dome Rock Mountains nearly to Colorado River, where usually there is an abrupt descent of 100 feet to the river bottom lands.

Many shallow arroyos or washes drain to Colorado River, but none of them carries surface waters. Of these, Tyson Wash and Arroyo La Paz are the most prominent. Tyson Wash, with a length of 50 miles, heads south and west of Quartzsite in several branches, which unite and drain northward to the north end of the Dome Rock Mountains, where the channel turns sharply westward and debouches on the Colorado River bottom lands. Tyson Wash carries an underground water flow at Quartzsite, where small tracts are irrigated from shallow wells operated by windmills or small gasoline pumps. Arroyo La Paz heads in the Dome Rock Mountains and for most of its course forms the southern boundary of the Colorado River Indian Reservation. The water supply in the vicinity of the placer camps is very scanty. Water of a rather inferior quality is furnished by Gonzales well, near the reservation line, and a small or uncertain supply is obtained from "tanks" or holes eroded in the bedrock of arroyos. Of these, Goodman tank is the best known and most accessible, but even this water must be piped from depths of several feet from the sands that fill the excavation. The placers in the Plomosa Mountains were supplied with water through pipe lines leading from the wells near Quartzsite.

The climate of the region is extremely arid. The mean annual precipitation at Parker,[1] near the north end of the reservation, is

[1] Bancroft, Howland, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: U. S. Geol. Survey Bull. 451, p. 13, 1911.

U. S. GEOLO



MAP SH

only 4.27 inches, and the mean annual temperature for a period of 12 years is 70.9° Fahrenheit. The summer is intensely hot, and work in the open is then almost impossible, but the winter is delightful. The vegetation of the region is scanty and includes no trees suitable for use as mining timber. The bottom lands of Colorado River support good growths of willow and mesquite and a few cottonwoods; in the larger arroyos there are sparser growths of thorny shrubs, including ironwood, ocotillo, palo verde, and mesquite; and on the bench lands and hill slopes there are several varieties of cactus and small shrubs.

GEOLOGY.

Character of the rocks.—In this investigation detailed geologic work was done only in the part of the Dome Rock Mountains that is included in the reservation, but the general geology of the Plomosa Mountains and the southern part of the Dome Rock Mountains is described by Bancroft.[1] Igneous and sedimentary rocks in complex association compose these mountains, and they range from pre-Cambrian schists and gneisses to Tertiary or Quaternary volcanic rocks. The placer areas specifically examined in the Dome Rock Mountains and in that part of the Plomosa Mountains here referred to are composed of intrusive igneous rocks, some of which are of schistose structure and others of holocrystalline granitic texture. The ages of these rocks could not be determined from the geologic evidence near by, although the schist is believed to be of pre-Cambrian age and the granite much younger and probably of Mesozoic age.

The ridges north of Tyson Wash are composed of intermixed schistose sedimentary and igneous rocks, into which are intruded narrow dikes of basic rocks, dikes and irregular masses of pegmatite and aplite, and an area of granite similar to that in the La Paz district. The metamorphosed sedimentary and igneous rocks are not differentiated on the map (Pl. IV). The rocks of sedimentary origin range from fine-grained silvery-white sericite schists to coarse-grained biotite schists with interbedded thin marble beds. Granite gneiss, amphibolite schist, quartz-epidote schist, and granite comprise the larger igneous masses in these ridges. Lava flows of Tertiary and Quaternary age occur throughout the eastern part of the Plomosa Mountains a short distance east of the area here considered.

Quartz-epidote schist.—A greenish-gray to black schistose porphyritic rock occupies the larger part of the Dome Rock Mountains within the reservation and probably much of the mountainous area east of the reservation. It forms relatively smaller areas of the ridges north of Tyson Wash. According to Bancroft it is the coun-

[1] Op. cit., pp. 22–36.

try rock in the vicinity of the New York-Plomosa placers east of Quartzsite. The rock is composed of quartz, orthoclase, and altered feldspars, some of calcic composition, more or less inclosed in an aggregate of epidote, sericite, chlorite, hornblende, and calcite. Locally magnetite is an important constituent. The rock exhibits varying degrees of schistosity, but large exposures show well-marked planes which trend from east-west to northwest-southeast and dip at an average of 30° to the north and northeast. The quartz-epidote schist is believed to have been derived from an intrusive igneous rock, probably a quartz monzonite or quartz diorite porphyry. This rock is of economic importance, for it contains the gold-bearing quartz veins in the La Paz district from which the placer deposits are derived.

Granite.—North of Goodman tank a light-colored granitic rock occupies a considerable area in the main Dome Rock Mountains and occurs in smaller masses in the ridges north of Tyson Wash. The rock is commonly of a medium-grained holocrystalline texture, but in places is coarsely granular, approaching a pegmatite. The crystals of quartz and feldspar are commonly intergrown. Orthoclase, oligoclase, and albite comprise the feldspars. Ferromagnesian minerals are variable constituents of the granite; in some localities they are practically absent or consist of sparsely distributed biotite and chlorite; in other localities hornblende, biotite, and chlorite are fairly abundant. The granite intrudes the quartz diorite and other schistose rocks of the region, and, as shown by the absence of dynamic metamorphism, is of much later age. The granite gneiss differs from the granite in composition by the arrangement of abundant biotite crystals in flow lines. Amphibolite and some of the biotite schists probably are derived from diabase and diorite.

Quaternary deposits.—Between the Plomosa and the Dome Rock mountains lies the gravel and wash covered desert of Quaternary deposits. Flanking the mountainous areas within the reservation, with their eastern limits undetermined, are the bench lands composed of unconsolidated sands, clays, and gravels deposited by Colorado River in Quaternary time during periods of aggradation. This bench-lands formation is correlated with the Chemehuevis gravel, as described by Lee,[1] who noted it at many places along Colorado River. Rapid erosion of the mountainous areas under desert conditions has produced thick wash deposits in the gulches and alluvial fans that extend for short distances from the base of the mountain slopes over the bench-lands formation. This material is unassorted and consists of angular rock fragments and sand. In the reservation

[1] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, pp. 43-47, 1908.

this wash is unconsolidated, but placer operators report that on the eastern slopes of the Dome Rock Mountains a cemented wash is overlain by incoherent material, and Bancroft reports that the placer workings in the Plomosa Mountains are in a conglomerate of the older rock fragments cemented by lime carbonate.

The bottom lands lying in the flood plain of Colorado River are deposits of river silt. During floods the plain is rapidly built up by fresh silt deposited from the heavily charged river waters.

PLACER MINES.

History.—Placer mining in this part of Arizona closely followed the discovery of the La Paz diggings. Part of the early history of these workings, in addition to that given by Mr. W. W. McCoy, was obtained from the report of J. Ross Browne in "Mineral resources of the States and Territories west of the Rocky Mountains," published in 1868. In January, 1862, Capt. Pauline Weaver was trapping along Colorado River, and at times would stray off into the mountains on prospecting trips for gold. The Indians, with whom he was on friendly terms, gave him some nuggets and, after Weaver had organized a party from Yuma, conducted him to the source of the gold. The party picked up $8,000 in nuggets within a short time, but had to return to Yuma, 150 miles distant, for provisions. A rush from southern California and Arizona points immediately started for these placers, and within a short time hundreds of miners were prospecting the country around the original location.

The town of La Paz was established at the base of the bench lands near the river, the houses being constructed of adobe bricks. La Paz soon became the supply point of the surrounding region, and maintained its population of about 1,500 until 1864, when, with the apparent exhaustion of the placers and the discovery of new diggings, large numbers left the district. From this time the population steadily decreased, until, with the creation of the additions to the Colorado River Indian Reservation in 1873, 1874, and 1876, which included much of the placer ground and greatly restricted mining, La Paz was practically deserted, and the site of the once flourishing town is now marked only by disintegrating adobe buildings.

The old placer workings are in the gulches and on the western hill slopes of the Dome Rock Mountains, from 6 to 8 miles from La Paz. Water at the diggings had either to be hauled from La Paz or a small supply obtained from the Goodman tank. Mr. McCoy states that water packed from La Paz to the placers brought $5 a gallon during the rush period. The gold was recovered entirely by dry washing in gold pans or wooden bowls called "bateas." Picks

and shovels were used to break up and handle the gold-bearing material, these implements being supplemented by Mexican miners by a steel bar 2 feet long. With such crude methods, it is apparent that only the coarser gold could be saved and only ground extremely rich would be payable. Nevertheless, it is estimated[1] that $1,000,000 was recovered in the first year, and as much more in each following year until 1868. Since that time the production probably has been comparatively small. The gold particles or nuggets ranged in value from 5 cents to $10, although $20 and $40 pieces were not uncommon, and the largest piece, or "chispa," taken out, found by Juan Ferrar, was valued at $1,160. The production per man per day frequently exceeded $100. With the introduction of the "dry-washer" machine, a few years after the district was discovered, greater quantities of material could be handled and a large saving of the gold effected, although by that time the richer ground had largely been worked over.

Dry-washer machines.—The machines used in "dry washing" are of several types, but probably the most efficient is that of the "bellows" type. In capable hands 6 cubic yards of material can be handled by a machine of the largest type by one man in eight hours, and the capacity of those of the smaller types, more commonly used, is 2 yards a day. The machine consists of a wooden framework, to which is attached a coarse screen, hopper, crank and gears, riffle board, and bellows. The material is passed through a screen having a quarter-inch mesh into a hopper having a capacity of 1 cubic foot, and then passes on to the inclined riffle board, 10 by 20 inches, which also is a screen surface with wooden riffles at right angles to its length. The pulsations of the bellows keeps the material in motion. Underneath the riffle board is a muslin cloth, stretched over the air chamber. The power for operating the bellows is a crank on geared wheels, and as the material passes over the riffle board the heavier particles are intercepted by the riffles and drop through the screen on to the cloth, while the waste material passes over the end of the board or is blown away by the air blast. The gold is obtained by panning the concentrates. It is apparent that the gold-bearing wash must run well above 50 cents per cubic yard in order that the operator may make miner's wages. Sporadic placer mining has been done with this machine by the miners at Quartzsite, but because of the variability of the gold content of the wash and the limitations of the machine no large areas have been thoroughly or continuously worked.

Areas of gold-bearing wash.—In the La Paz district the principal gulches or arroyos in which the gold-bearing wash occurs or to which

[1] Browne, J. R., Mineral resources of the States and Territories west of the Rocky Mountains, 1868.

the richest gulches are tributary are Goodman Arroyo and Arroyo La Paz, an arroyo at the southern boundary of the reservation. Ferrar Gulch, tributary to Arroyo La Paz, contained the richest and most productive placers of the district. Evidences of former work are seen in the old excavations and piles of bowlders and angular rock fragments, in exposures of bedrock where the wash was shallow, and in the deeper deposits by old shafts from which small drifts were driven in the hope of finding rich pockets. The thickness of the gold-bearing wash is variable, ranging from a few feet on the mountain slopes to an unknown measure in La Paz Arroyo and in the gulch traversed by the Quartzsite-Ehrenberg road. Shafts have been sunk in the wash to depths of 30 feet without reaching bedrock and it is reported that in places the wash is at least 60 feet deep. By far the greater part of the auriferous material is unworked, especially that in the lower courses of the arroyos, where the wash is deep. Ferrar Gulch for most of its course has been practically worked out. No estimate could be made of the probable gold content of the wash in the La Paz district because of lack of detailed data and of uncertainty as to the limits of the wash, but in one area the deposit, said to contain values of 50 to 75 cents per yard and much of it 30 feet or more deep, occupies at least 640 acres, and considerable areas extend into the smaller gulches.

Character of gold-bearing wash.—The gold-bearing material consists of sand and clay inclosing angular rock fragments of greatly variable size. Tests indicate that about 20 per cent of the wash will pass through a quarter-inch screen, and the largest bowlders weigh several hundred pounds. The material near the surface is unassorted and is unconsolidated, being readily worked with pick and shovel. That at depths of 15 or 20 feet is consolidated, but the cementing substance readily disintegrates on exposure to air. Deposits of wash below the depths of test pits may prove to be similar to the outwash on the east slope of the Dome Rock Mountains and in the Plomosa placers, where the material is firmly cemented with calcium carbonate and requires crushing in order to free the gold. In Goodman Wash below the Goodman tank a deposit of calcareous tufa several feet thick was noted. The ground stands sufficiently well to permit the sinking of shafts without the use of timber. The wash is readily worked in dry-washer machines, the only requirement being that the ground must be dry. The gold is said to be distributed throughout the wash, though in the early workings the richest yield was obtained near bedrock. The size of the gold now recovered from the deposits of the La Paz district probably averages only a few cents, but, as already stated, the gold recovered from the early workings was much coarser. The gold is rough and angular, and particles of iron cling to some of the nuggets. Magnetite is always found in

the concentrates, and bowlders of magnetite, the largest weighing several pounds, are frequently found on the surface.

Present and contemplated operations in the La Paz district.—Occasional dry washing is done by miners within the La Paz district, and yearly assessments are maintained by parties who hope to gain title to placer tracts when the restrictions on mining within the reservation are removed. The most extensive preliminary work has been done by a California company, which, in addition to making tests, has leveled the top of a small hill for a reservoir site. This site, which stands at an elevation of 850 feet, is about 600 feet above the Colorado River bottom lands. Water for the reservoir could be obtained from wells near La Paz, which in an air line is but 4½ miles distant. It is said that the company intends to hydraulic the gold-bearing wash from the smaller gulches and hillsides into the larger arroyos, where a dredge will be installed and the entire deposit systematically worked.

Placers on the east slope of Dome Rock Mountains.—There are several placer tracts on the east side of the Dome Rock Mountains in the large branch of Tyson Wash, west of Quartzsite, and in low-lying ground traversed by gulches tributary to it. Of these the Middle Camp, Orofino, and La Cholla placers are outlined roughly on the accompanying map. These placers have been worked intermittently on a small scale since the La Paz placers were discovered, and several attempts have been made to handle the ground on a large scale, but thus far these efforts have proved unsuccessful. At the time the region was visited the Orofino tract, owned by the Catalina Gold Mining Co., was the only one on which work was being done, and this work consisted of testing the ground, partly to determine its gold content and partly to determine the advisability of working the wash with dry concentrating machines of large capacity. The following information was obtained on the ground, the data as to the gold content and like matters being supplied by Mr. E. L. Dufourcq, the engineer in charge. The placer ground owned by this company comprises 640 acres of land in which test holes were sunk every few hundred feet. The holes ranged in depth from a few feet to 30 feet. The material taken from each excavation was run through a small concentrator to determine its gold content, and the results showed that the gold content ranges from a few cents to over $1 per cubic yard, the average being 38 cents. The colors run from less than 1 cent to 24 cents each and the gold is fine, being worth about $19 an ounce. The gold-bearing material differs from that of the La Paz placers in that it consists of unconsolidated rock débris and an underlying cemented gravel. The loose material ranges in depth from a few feet to 12 feet, and the cement is of variable depth—at least 18 feet in places. The gold is said to be distributed through

both the unconsolidated and the cemented material. The machine used in making the tests was a Stebbins demonstration dry concentrator. This machine consists of a metal frame on which is a perforated steel table with riffles parallel to its length. Underneath the table is a fan which supplies an air blast that is conveyed in a tube to the table and passes out through the perforations. The dry wash is screened through a quarter-inch mesh at the head of the table, and as the material passes onto the table the lighter particles are blown away or worked over the lower side and the concentrates are collected at the end. The power is a small gasoline engine, which operates the fan and gives to the table a vibratory motion similar to that of a Wilfley table. Its capacity is about 1 cubic yard an hour.

The Middle Camp and La Cholla placer tracts were not visited, but their situation is similar to that of the Orofino tract, in the arroyos tributary to Tyson Wash. At the Middle Camp placer it is reported that a dry concentrating machine having bucket-dredge excavator and capacity of 1,000 yards per 10-hour day was installed, but proved a failure because of the moisture contained in the wash at depths of a few feet. In any dry concentrating process in order to attain maximum capacity and to make high saving of gold content it is essential that the material be absolutely dry, and even in this arid region some of the material holds sufficient moisture to greatly hamper the handling of large quantities of it. The bedrock of the La Cholla placer tract is reported to be schist derived from sedimentary rock. This schist is said to contain many small auriferous quartz veins, and the gold-bearing material is a hard siliceous cement that must be crushed before the gold can be recovered.

No survey was made of the placer ground on the east side of the Dome Rock Mountains, but the deposits are extensive enough to merit serious attention. It is believed that the deposits can be worked best by hydraulic methods, by means of storage reservoirs on one of the many small hills that overlook the placer ground. The water would have to be pumped from Colorado River with a lift of about 1,000 feet. The gold-bearing débris of the smaller gulches and mountain slopes could then be washed into the larger arroyos, where the entire deposit could be worked by dredge or by sluicing, although the slope of ground is rather low to permit easy disposal of the waste rock.

Deposits in the Plomosa Mountains.—Placer deposits on the southwestern slopes of the Dome Rock Mountains, 5 miles southeast of Quartzsite, have been worked intermittently on a small scale for many years. These placers were examined in 1909 by Howland Bancroft, and the following data are taken from his report.[1]

[1] Op. cit., pp. 87–88.

Of the companies that own placer tracts in this area, the New York-Plomosa Co.—

> has installed large machinery, laid a 7-mile water-pipe line without any expansion joints, and has got all ready to work the placers. For some reason only one run had been made prior to May, 1909, the results of which were not available. * * *
>
> There has been installed on the property the following machinery: Three 100-horsepower boilers, one 300-horsepower Corliss engine, two Williams mills, two Huntington mills, and various accessories. The pipe line which furnishes the water used on the property is approximately 7 miles long and is about 5 inches in diameter, the difference in elevation between the two terminals of the line being approximately 400 feet.
>
> The ground has been prospected by a great many small tunnels with frequent openings to the surface and an occasional larger adit tunnel run along the bedrock. The vicinity had previously been prospected by "dry washers," and consequently the underground work resembles a network of small burrowings, some of which a man can scarcely drag himself through. * * *
>
> In certain old drainage channels which led away from the southwestern part of the Plomosa Mountains is found an auriferous conglomerate of granite, schist, and quartz fragments cemented by lime carbonate. In thickness this conglomerate or "cement rock" varies from a few inches to a great many feet. * * * It was evidently the intention of the company to work the cemented material in mills.

A recent communication from Mr. Beggs states that these placers are again receiving attention, and that a dry concentrating plant, costing $60,000, is to be installed. Numerous tests have been made and a large area of ground has been blocked out, which is said to run 50 cents per cubic yard. Water in sufficient quantity for the needs of the camp was obtained in a well at a depth of 300 feet.

GOLD QUARTZ VEINS.

The auriferous quartz veins in the vicinity of the La Paz diggings were probably discovered at the same time as the placers, for in places they form conspicuous outcrops with abundant float. The decomposition of these veins has produced the placer gold for the largest areas of gold-bearing wash are found along the more persistent quartz veins on which mining has been done. These veins are generally distributed through the metamorphosed pre-Cambrian igneous and sedimentary rocks, although they are more numerous in the country rock of the La Paz placers than in the sedimentary schists. The veins are of two types—those that lie in the planes of schistosity and those that cut across them. In the La Paz district the veins of the first type are comparatively large and persistent, trending from east-west to northwest-southeast, and those of the second type consist of numerous north-south trending gash veins. On the west ridge north of Tyson Wash two large quartz veins of east-west trend cut

across the schistosity of the inclosing rocks, and other smaller veins trend in various directions. The larger veins of east-west trend have been mined or prospected, but those of the gash vein type, although reported to be gold-bearing, are too small for exploitation. The failure to develop these veins more fully is due to their remote situation and the inability of the owners to acquire title under the mineral laws, for all the prospects here described except one are within the reservation.

MINES AND PROSPECTS.

Goodman mine.—The Goodman mine is on the Goodman vein, which trends from northwest-southeast to east-west and can be traced for 3 miles, its eastern limits of outcrop being the wash-filled arroyo traversed by the Quartzsite-Ehrenberg road, and the faulted portions of its westward extension being traceable to the bordering bench lands about a mile south of the Goodman tank. The vein varies greatly in width, ranging from a mere seam to a vein 40 feet wide and averaging in width probably 10 feet. It occupies a shear or fault zone in the quartz-epidote schist. It dips generally to the north at angles ranging from 30° almost to 90°. The development consists of several inclined shafts sunk on the vein and connecting tunnels. One incline is 120 feet deep with connecting tunnel 140 feet long and 120 feet of drifts; another tunnel is 240 feet long. The vein material is a massive iron-stained quartz containing small cavities resulting from the weathering of pyrite, which is distributed through the vein but is usually more abundant along the walls and for a short distance in the inclosing wall rocks than elsewhere. The gold is contained in the pyrite and can at many places be seen in the oxidized ores. About $40,000 was obtained from the Goodman mine prior to 1900, and since that time Mr. W. E. Scott, of Quartzsite, has mined ore to the value of $9,000, the average tenor of which was $65 per ton. The ore was hauled 15 miles to Quartzsite and there treated in a small amalgamation mill. The mine is not worked at present, although yearly assessments are maintained.

Golden Hope claims.—The Golden Hope claims are on the Goodman vein near the east reservation line. The workings consist of two shafts, each about 30 feet deep, and two tunnels, 30 and 70 feet long, respectively, which cut the vein at shallow depths. In a recent communication Mr. Beggs stated that a large shoot of milling ore running $30 per ton in gold had been opened in these workings and that the company owning the property was contemplating the erection of a mill to treat the ores.

The west end of the Goodman vein is covered by claims located by Mr. Beggs, who stated that he obtained an assay of $200 per ton

in gold on ore taken from a small discovery hole sunk on the vein. The vein at the west end is of irregular shape; in places it is 40 feet wide but in a short distance pinches to a mere seam or is cut out by faults. The inclosing wall rocks are crumpled and folded quartz-epidote schists.

Mariquita prospect.—This property was not examined by the writer but is described as follows by Bancroft:[1]

The Mariquita prospect is located about 6 miles west of Quartzsite, the road leading to it branching from the Ehrenberg stage line some 4 miles out of Quartzsite. It is situated 2 miles north of the stage road, at an elevation of 1,100 feet on the southeastern side of a saddle which occurs midway in the Dome Rock Mountains.

Medium to fine grained quartz-mica schists, apparently intruded by much younger fine to medium grained granites or quartz monzonites, are the rocks in the immediate vicinity. The schists strike northwest-southeast and dip 20° NE., and they contain, besides the quartz and mica, much epidote and chlorite, with a large percentage of orthoclase feldspar and some unaltered but contorted biotite crystals.

A fairly large vein of quartz, carrying a little copper and gold, which has been roughly prospected, is the source of the ore extracted from this property. The vein strikes S. 20° E. and dips 20° NE., and lies in a slip or fault between parallel schist strata. In width the vein varies from a few inches to several feet, is fairly persistent in length, and apparently is lenticular. As the workings on the property are old and not very extensive, little accurate data on the size of the ore body were obtained.

Dan Welsh prospect.—The Dan Welsh prospect is on the summit of a ridge near the south boundary of sec. 32, T. 6 N., R. 21 W. Little work has been done on it, and it was deserted at the time of the writer's visit. The development consists of a shaft 12 feet deep and several open cuts and short tunnels, which explore a quartz vein whose average width is 2 feet. The vein trends east-west, dips from 60° N. to vertical, and can be traced 1,000 feet, pinching to a mere seam on the west side of the ridge 400 feet from the shaft and disappearing beneath outwash deposits on the east side of the ridge. The inclosing wall rocks are a sandy mica schist of sedimentary origin and granite gneiss and amphibolite schist of igneous origin, all of pre-Cambrian age. The schists trend about north-south and dip 20° E., and the fracture filled by the quartz vein cuts squarely across the schistose structure. The vein matter is a massive vitreous, iron-stained quartz containing plentiful disseminated pyrite cubes from an eighth to a quarter of an inch square or crystal aggregates an inch or more in diameter. The oxidized portion of the vein, which extends to the bottom of the shaft, contains cavities from which pyrite has been weathered. The iron oxides contain here and there specks of gold and along the fracture planes in the quartz there are

[1] Op. cit., pp. 81–82.

dendritic flakes suggesting secondary deposition. The ore is apparently of high grade; its exact tenor is not known. A stack of 50 sacks of ore was found in the gulch leading down from the prospects on the west slope of the ridge, and another pile of 20 sacks, with several tons of unsacked ore, was found at the shaft. It was reported that the owners of this prospect packed the ore to Colorado River, 6 miles distant, and there treated the ore in an arrastre with mercury to recover the gold, but they were not allowed to continue operations.

Mammoth prospect.—The Mammoth prospect is in sec. 12, T. 5 N., R. 21 W., near the base of an eastward-trending ridge. An old incline, now inaccessible, but probably several hundred feet deep, is sunk on a faulted quartz vein of variable width, which trends about N. 70° E., and is traceable to the west for 1,000 feet, mainly by abundant float. At the shaft the vein is 10 feet wide. No work has been done here in recent years, but in 1914 the prospect was relocated and is now known as the Apache No. 2. The country rock is a dark schistose porphyry containing prominent feldspars inclosed by biotite, chlorite, and epidote. The vein matter is a massive white quartz slightly stained with iron and copper salts, with sparsely disseminated pyrite. The ore is said to be valuable only for its gold content, but its tenor is not known.

SOME CINNABAR DEPOSITS IN WESTERN NEVADA.

By Adolph Knopf.

DEPOSITS EAST OF MINA.

LOCATION AND HISTORY OF DISCOVERY.

A belt of cinnabar deposits is situated in the heart of the Pilot Mountains, in an air line 8 miles south of east of Mina, Esmeralda County, Nev. The average elevation above sea level here is 7,300 feet, or about 2,700 feet above Mina, the local supply point, which is on the Southern Pacific system. The deposits are accessible from Mina by a good wagon road of easy grade about 12 miles long. The area in which the quicksilver deposits occur supports sufficient forest growth to furnish wood for local use as fuel and contains a number of springs that are capable of furnishing an ample domestic supply of water. The topographic features of the district and its approaches are shown on the scale of 1:250,000, or approximately 4 miles to the inch, on the United States Geological Survey's map of the Tonopah quadrangle.

The discovery that drew attention to the cinnabar of Pilot Mountains was made in June, 1913. On the day of the discovery Thomas Pepper and Charles Keough had been tracking two stray steers, when near nightfall the trail led over an old prospect in which a face of limestone traversed by small veinlets of red mineral was exposed. The red mineral was recognized by Keough as cinnabar. After finding the steers and taking them to Mina the two discoverers returned to Cinnabar Mountain, as the hill on which they had made the find has since been named, where they spent 10 days in careful search and located 17 claims. On June 18 they went back to Mina and made known their find, causing an intense excitement, and that afternoon almost every citizen of the town left for the site of the discovery by automobile and by other less expeditious conveyances. A large number of claims were staked by the first comers and many more were afterward staked by claimants from Tonopah. Unfortunately the amount of exploratory and development work has not been proportional to this early enthusiasm.

The discovery was widely heralded as the rediscovery of the "lost Hawthorne quicksilver mine," named for Judge Hawthorne, in whose

honor it is said Hawthorne, the seat of Mineral County, is named. According to local report Judge Hawthorne discovered in the seventies a rich quicksilver deposit, which is believed to have been situated at the site of the recent discoveries. In returning from the mountains, so it is said, Hawthorne lost his bearings, and although he attempted annually to the end of his life to find the "quicksilver mine" he remained unsuccessful. This tradition seems highly improbable. The original discoverer—who he was is unknown—had done some very substantial exploratory work on the prospect. In his efforts to prove his find he had blasted out a considerable mass of solid limestone, and as further tokens of his activity sticks of powder, fuse, and picks lays abandoned at the prospect. That this energetic prospector lost his way and was unable to find the prospect at which he had labored is not easily credible. It is more likely that he abandoned the prospect as, in his judgment, not sufficiently valuable.

The newcomers have found considerably richer deposits than the unknown pioneer did, and have shown that the cinnabar extends along a considerable belt.

GENERAL GEOLOGIC FEATURES.

Cinnabar has been found at a number of places along a belt that is about 2 miles long and trends northeastward. The main area comprises the hill known as Cinnabar Mountain. Limestones make up the bulk of this hill, although some dolomitic graywacke, composed of angular and rounded quartz grains and of angular chert particles embedded in a cement of dolomite, is interstratified with them. The strike ranges from north to northeast, and the dip from 40° to 70° NW. The limestones carry crinoid fragments and other obscure fossils, and are probably of Paleozoic age. North of Cinnabar Mountain graywacke, slate, and chert form the country rock. No igneous rocks, in either dikes or flows, have been found near the mineral deposits. Tertiary lavas appear on the north flank of the mountains, but they are 4 or 5 miles from the cinnabar belt.

The cinnabar deposits on Cinnabar Mountain occur in fracture zones in limestone. The limestone is traversed by thin veinlets of white spar, and the cinnabar is intergrown with the calcite or dolomite of the veinlets or occurs as a replacement of the adjoining wall rock. The intimate penetration of the cinnabar into the body of the limestone is locally a notable feature. Stibnite is associated with the cinnabar at one locality only; pyrite and marcasite, characteristic associates of quicksilver ores the world over, do not occur in the district.

The geologic features of the quicksilver deposits north of Cinnabar Mountain are somewhat different. At the Cinnabar King prospect

the ore consists of cinnabar in a gangue of barite and the deposit is inclosed in a country rock of brecciated chert. Farther north, at the Red Devil prospect, the country rock is graywacke and the cinnabar is disseminated through a siliceous gangue.

Although highly encouraging showings of cinnabar ore have been uncovered at a number of places in the district, the amount of prospecting so far done is insufficient to prove that the linear extent of any deposit, let alone its persistence in depth, is great enough to indicate its commercial importance. The geologic features of the deposits appear to be favorable to persistence of the ore in depth of the grade and character of that at the outcrop, for the mineralization is obviously of a kind in which the deposition of the cinnabar was not dependent on immediate proximity to the surface, as it is, for example, in quicksilver deposits that are formed at the vents of hot springs.

The prospects at which the most exploratory work has been undertaken will now be described.

FEATURES OF THE PROSPECTS.

Lost Steers group.—The Lost Steers group consists of 11 claims owned by Thomas Pepper and Charles Keough. The most development work so far accomplished in the district has been done on the claims of this group. At the lowest workings a tunnel about 75 feet long has been driven, but its course is such that it fails to undercut the ore exposed at the surface.

A zone several hundred yards long, extending from the mouth of the tunnel on the north to the open cut made on the summit of the mountain by the pioneer prospector, carries cinnabar at intervals. The geologic features are essentially similar at the different exposures. The country rock is a fine-grained dark limestone, which is cut by veinlets of white spar and is sporadically impregnated with crystallized cinnabar. Locally the cinnabar without any associated gangue mineral replaces the limestone, and such occurrences constitute a very high grade of ore. At one locality some bunches of stibnite have been found, but elsewhere cinnabar is the only sulphide mineral in the deposits. At the different occurrences of cinnabar along the zone there is evidence that fracturing of the limestone was of importance in the genesis of the ore. For example, at the shaft, which is about 6 feet deep, two fairly well defined walls, 52 inches apart, can be seen. They trend N. 40° W., and the footwall, which is the better defined of the two, dips 70° SW.

The cinnabar shown in the open cut on the Lost Steers claim No. 1 occurs in a different fracture system from the one just described. The deposit on this claim lies on the east side of the summit of Cinnabar Mountain. The limestone country rock strikes north and dips

40° W. An excellently defined wall, striking north 45° W. and dipping 70° NE., forms the footwall of the deposit. The limestone lying upon this wall is reticulated with sparry veinlets of calcite carrying cinnabar, which occurs locally in considerable masses characterized by splendent cleavage faces. The system of cinnabar-bearing calcite veinlets extends at least 6 feet from the footwall. Rarely streaks of ore make out into the footwall zone.

Keg and Barrel prospect.—An open cut at this prospect shows a well-defined wall striking N. 30° E. and dipping 70° W. The country rock—a fine-grained dark dolomite—under this wall is netted with white veinlets of dolomite averaging a fourth of an inch in thickness. Coarsely crystallized cinnabar occurs in the veinlets to some extent, but mainly as a replacement of the adjoining country rock.

Cinnabar King prospect.—The Cinnabar King prospect is a short distance north of Cinnabar Mountain. The exploration work so far done consists of a small pit, which affords but inadequate information as to the nature and extent of the occurrence of the ore. This exposes the face of a body of ore, about 4 feet thick, dipping 20° N., as far as can be determined by the small developments. The ore consists of barite carrying disseminated cinnabar and averages perhaps 4 per cent of quicksilver. The general country rock, unlike that of Cinnabar Mountain, is a highly fractured chert.

Red Devil prospect.—This prospect, owned by A. C. Roach, Eugene Grutt, and A. Drew, is about 1½ miles north of Cinnabar Mountain. A shallow open cut discloses a body of good grade ore, 30 inches thick, apparently dipping at a low angle to the west. The ore consists of ocherous cinnabar in a fine-grained siliceous gangue. The country rock is a coarse graywacke made up largely of flat angular fragments of black slate.

DEPOSITS EAST OF BEATTY.

SITUATION AND DISCOVERY.

A number of quicksilver deposits are situated 6 miles east of Beatty, Nye County, Nev., the junction of the Tonopah & Tidewater and the Las Vegas & Tonopah railroads. The quicksilver-bearing area lies in the Fluorine mining district. The prospects fall into two groups, one on the east slope of Bare Mountain and the other on the northern end of Yucca Mountain, 3 miles northeast. Locally the part of the Bare Mountain group of hills on which the quicksilver prospects occur is known as Meiklejohn Mountain. The area is readily accessible by roads of easy grade. The topographic features of the area are shown on a scale of 1:250,000 on the United States Geological Survey's map of the Furnace Creek quadrangle.

At the time of the principal activity at Rhyolite, in the years immediately following 1905, prospectors spread out into the neighboring territory. The east flank of Bare Mountain was the scene of considerable activity in the search for gold, and on the Grochon claim high-grade gold ore, said to carry tellurides, was found. This ore occurs in a small irregular vein of fine-grained quartz showing no metalliferous constituents, but the lowest assays are reported to have run as high as $84 a ton in gold. This created much excitement at the time, and the camp that sprang up here was named "Telluride." Quicksilver ore was discovered in place on the east flank of Bare Mountain by J. B. Kiernan and A. A. Turner in 1908, although indications of cinnabar had been found somewhat earlier. Attention having thus been drawn to the occurrence of quicksilver, it was soon shown to have a considerably wider distribution. In 1912 a 10-ton Scott furnace was built in Gold Gulch by the Telluride Consolidated Quicksilver Mining Corporation. It is on the northeast slope of "Financier Hill," as it is locally known, one of the low hills at the northern end of Yucca Mountain, where this range merges into the hills of the Bare Mountain group. A tunnel some 1,100 feet long, starting near the furnace, was driven under this hill, which, it is said, was thought to contain $22,000,000 worth of ore, but no ore was found. The company then leased a number of properties on Meiklejohn Mountain and operated them, hauling the ore by teams to the furnace, a distance of 4 miles. In August, 1914, the company became involved in financial difficulties, its property was attached, and all work was suspended. At other places in the district a small amount of prospecting was in progress during 1914.

GENERAL GEOLOGIC FEATURES.[1]

The general country rock of the quicksilver-bearing area on the east slope of Bare Mountain is a fine-grained gray dolomite. It is rather massively bedded and has undergone considerable disturbance, so that its stratification is not readily discernible, but south of Telluride camp the beds dip 20° N. The age of the rocks, as determined from fossils embedded in a block of dolomite kindly sent to the Geological Survey by Mr. A. A. Turner, is Silurian. Dr. Edwin Kirk reports that the fossils include the species named below:

Thecia major.	Syringopora sp.
Coenites verticillata.	Conchidium (2 species).
Favosites cristatus.	Pisocrinus sp.

[1] The broader features of the geology and their relation to those of the surrounding territory have been discussed by S. H. Ball in A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, 1907.

Dr. Kirk adds:

This collection is of considerable interest, as it fixes rather definitely the age of the widespread Silurian fauna of the Western States. The beds correlate approximately with the Fusselman limestone of the El Paso region and the Laketown dolomite of Utah. On the evidence of the fossils in the present lot it is safe to place the fauna near the top of the Niagaran.

At the base of Bare Mountain a narrow belt of quartzite appears between the dolomite and the upper edge of the piedmont alluvial slope.

The rocks are cut by a number of porphyry dikes. Large phenocrysts of quartz are prominent constituents of the rock of these dikes. In fact, after the dike rock has become scarcely recognizable from decomposition, as it commonly does, only the quartz crystals are distinguishable and serve to reveal the identity of the altered rock. Feldspar and biotite also appear among the phenocrysts. Examination under the microscope of some of the better preserved material from the Columbia dike—which, however, has been altered by the development of pyrite, dolomite, and chlorite—suggests that it is a quartz diorite porphyry. The dikes are possibly related in origin to the igneous masses represented by the pegmatites that are common in the northern part of the range.[1]

The quicksilver-bearing area north of Meiklejohn Mountain is underlain by a gently dipping succession of rhyolite flows and tuffs. They are part of the rhyolite series exposed in the Bullfrog district, where they attain a thickness of more than 6,000 feet.[2] They are thought by Ball to be of early Miocene age.

The quicksilver deposits inclosed in the dolomite consist of masses of opal or of cryptocrystalline silica carrying cinnabar; those inclosed in the rhyolites consist of masses of opal and alunite carrying cinnabar. The deposits contain no other metallic sulphides, such as pyrite, marcasite, or stibnite, which are generally associated with quicksilver ores. The gangue commonly contains large bodies, in places as much as 10 feet thick, consisting of a soft white substance, which, as shown by an analysis made by R. K. Bailey in the laboratory of the Geological Survey, is a nearly pure hydrated silica, namely, silica, 90.46 per cent; water (loss on ignition), 5.38 per cent. This substance is accordingly a pulverulent variety of opal. Although opal of the hard, massive kind is the predominant gangue mineral of the deposits, various forms of cryptocrystalline silica, comprising chalcedony and exceedingly fine grained quartz also occur. Locally all three of these forms of silica are intimately associated in the same deposit. The only departure from the prevailing

[1] Ball, S. H., op. cit., pp. 155–156.

[2] Ransome, F. L., Emmons, W. H., and Garrey, G. H., Geology and ore deposits of the Bullfrog district, Nevada: U. S. Geol. Survey Bull. 407, p. 31, 1910.

simple mineralogy of the district is that shown by the deposit cut in the Banner tunnel. This consists of a chimney, a few feet in diameter, of shattered dolomite cemented by coarsely crystalline calcite and barite and carrying a small amount of cinnabar.

The quicksilver ore occurs in irregular, erratic shoots in the siliceous masses. In the dolomite the bodies of opal and cryptocrystalline silica are commonly small and are erratically distributed; in the rhyolite, however, the opalized belts extend for a thousand feet or more and attain widths of as much as 200 feet. In the opalized rhyolite the quartz phenocrysts only have remained intact; the sanidine phenocrysts have been transformed largely into alunite, the hydrous sulphate of aluminum and potassium, and the rest of the rock has been converted into opal, or into pulverulent hydrated silica, with which is associated a notable amount of alunite. The opalized condition of the rhyolites is readily recognizable by the unaided eye, but the presence of the alunite becomes manifest only under the microscope. The optical determination of the alunite was verified chemically by its sulphate reaction. In spite of the profound alteration of the rhyolite, it retains with remarkable distinctness the normal appearance of an igneous rock.

This occurrence of alunite with cinnabar is of scientific interest, for this mineral has not heretofore been recorded in association with quicksilver ores. It has, however, been described as occurring in considerable quantity in the sulphur deposits resulting from the solfataric alteration of rhyolite tuffs at Rabbit Hole Springs, Nev., and these deposits contain traces of cinnabar.[1] At Goldfield, which is 65 miles northwest of the quicksilver deposits near Beatty, alunite is an abundant constituent of the gold ores. A quicksilver deposit occurs at Goldfield; but, singularly enough, this deposit, believed by Ransome[2] to be a result of the same mineralization that produced the gold lodes, or one closely preceding or following it, does not contain alunite, the mineral so characteristic of the district.

The cinnabar in the deposits east of Beatty is not present in quantities proportional to the amount of opalization and alunization, however, but occurs sporadically throughout the belts of altered rhyolite. A more thorough prospecting of these belts than has yet been attempted appears advisable.

FEATURES OF THE PROSPECTS.

Cinnabar prospect.—The Cinnabar prospect, owned by the Denver-Bullfrog Mining Co., is on the southeast side of Meiklejohn Moun-

[1] Adams, G. I., The Rabbit Hole sulphur mines, near Humboldt House, Nevada: U. S. Geol. Survey Bull. 225, pp. 499–500, 1904.

[2] Ransome, F. L., Geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey Prof. Paper 66, pp. 113, 174, 1909.

tain. The principal development work is a tunnel 200 feet long, which intersects the cinnabar deposit at a depth of 100 feet. From the portal of the tunnel a gravity tram extends to the base of the mountain, 600 feet below. A D retort, with a capacity of 800 pounds in 12 hours, has been installed on the property, and some flasks of quicksilver have been produced. The ore body has been worked mainly, however, under lease to the Telluride Consolidated Quicksilver Corporation, which hauled the ore to their furnace on Gold Gulch.

The country rock inclosing the ore body is a hard, fine-grained arenaceous dolomite. At the outcrop the cinnabar-bearing deposit has a length of about 125 feet; in the tunnel below, about 70 feet. Opal is the principal gangue mineral. A great mass of opal, generally milk-white in color and more or less porous and cavernous in structure, is exposed in the tunnel. In this opal there are large pockets filled with soft, white hydrated silica, an analysis of which is given on page 64. Some of these masses of silica are 6 to 10 feet thick. Chalcedony forms an insignificant proportion of the opal mass. Locally the opal containing cinnabar is of gem quality, and some of this material has been polished and placed on the market.

The cinnabar is either inclosed in the opal as massive mineral or is so very finely disseminated through the opal as to give it a blood-red color. Some of the high-grade cinnabar ore, as determined under the microscope, proves to be a replacement of arenaceous dolomite. Some of the replaced rock, in fact, contains sufficient detrital quartz to be a dolomitic sandstone. The quartz grains, many of which are perfectly rounded, have remained intact, but the dolomite cement in which they were embedded has been replaced by chalcedony, opal, and cinnabar. Only rarely has a little quartz been deposited in optical continuity with the detrital quartz grains.

Early Bird prospect.—The Early Bird prospect, which is owned by the Telluride Consolidated Quicksilver Mining Corporation, is on the north flank of Meiklejohn Mountain, near its base. A large reef of cryptocrystalline silica projects prominently above the inclosing limestone; it is several hundred feet long and at its maximum is over 100 feet wide. It contained a short, narrow shoot of high-grade cinnabar ore, which has been largely removed through an adit cutting the reef at a shallow depth.

Mammoth group.—The claims of the Mammoth group (Nos. 1, 2, and 3), owned by the Telluride Consolidated Quicksilver Mining Corporation, extend along a belt of opalized and alunitized rhyolite trending N. 30° W. At its south end this belt is several hundred feet wide. The main work has been done on Mammoth No. 2, where a tunnel 50 feet long was driven into a porous, cavernous siliceous mass, evidently representing a place of more intense alteration of the

rhyolite. A number of open cuts and shallow shafts have been excavated at other points, but no extensive bodies of quicksilver ore have so far been found.

Mammoth No. 5 claim.—The Mammoth No. 5, owned by J. F. Grant and associates, is situated on another belt of silicified rhyolite, which lies somewhat west of the Mammoth group of the Telluride Consolidated Co. It is said to be traceable for more than 1,000 feet, but has been prospected only by a few shallow open cuts. The ore masses consist of a soft white material—hydrous silica mixed with opal and alunite—carrying finely disseminated cinnabar. This is traversed by irregular veins and masses of white opal and chalcedony. The ore material at the main prospect trench is the product of the transformation of porphyritic obsidian by siliceous cinnabar-bearing solutions.

In places along the belt of silicified rhyolite outcrops of chalcedony and opal as much as 50 feet wide appear. Although the best ore so far found occurs in the soft, pulverulent material, some cinnabar is locally inclosed in the hard siliceous reefs.

RELATION OF THE CINNABAR DEPOSITS TO THOSE OF THE QUICKSILVER BELT OF WESTERN NEVADA.

The existence of a quicksilver-bearing belt in western Nevada, in Humboldt, Esmeralda, and Nye counties, has long been recognized. The information concerning the cinnabar deposits of this belt has recently been assembled by McCaskey,[1] who contributes also a description of the ore bodies at Ione, in Nye County, the locality from which the principal production has so far been derived. The deposits east of Beatty described in the present report extend the quicksilver belt considerably farther south.

The general tendency of those who have described the deposits of this belt has been to regard them as genetically connected with the Tertiary and Quaternary volcanism of the province. The phenomena observable at Steamboat Springs support this conjecture. The hot waters issuing from these springs deposit a siliceous sinter which contains cinnabar and amorphous red antimony sulphide, together with lesser quantities of other metallic sulphides. According to Becker[2] the deposits have formed close to the edge of a basalt flow and probably result from the volcanic action of which the lava eruption was one manifestation. He believes that the water issuing from the springs comes from the Sierra Nevada; that it descends to great depths, where it becomes heated by contact with subterranean masses of hot basalt, and ascends along the fissures by which the lava

[1] McCaskey, H. D., Quicksilver: U. S. Geol. Survey Mineral Resources, 1911, pt. 1, pp. 906–909, 1912.

[2] Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: U. S. Geol. Survey Mon. 13, pp. 338–350, 1888.

reached the surface. Concerning the genesis of the other quicksilver deposits of the western Nevada belt, opinions have been less precisely formulated, although, as already mentioned, these deposits also are regarded as of " volcanic origin," but probably this term is now used in a sense different from that which Becker had in mind.

It is difficult, however, to show that some of the deposits are related to the Tertiary volcanism of the province. Ransome,[1] in fact, is inclined to regard the quicksilver deposits of the Humboldt Range as of early Cretaceous age. The same difficulty inheres in any attempt to connect the cinnabar deposits east of Mina with Tertiary eruptive activity. On the other hand, it is interesting to note that a quicksilver deposit, clearly of Tertiary age, occurs in the volcanic rocks at Goldfield, which is midway between Mina and Beatty.[2] The deposits near Beatty are rather obviously associated with the Tertiary volcanism of that region. This association raises an important problem, for in the Bullfrog district, a few miles west of Beatty, the gold deposits, according to Ransome,[3] are genetically connected with this same general outburst of volcanism, though it was not found possible to link the ore deposition with any particular one of the many magmas that solidified as the lavas now exposed in the district. Among the most noteworthy facts shown by the study of the district is the remarkably feeble chemical alteration of the wall rocks of the ore bodies; and it was therefore concluded that the vein-forming solutions were dilute, cool, and under no heavy pressure. Now the notable feature of the quicksilver deposits in the rhyolites east of Beatty is the intense alteration of the rocks—their complete silicification and alunitization in belts hundreds of yards long and as much as 200 feet wide. This profound alteration points to the conclusion that the quicksilver-bearing solutions were under physical and chemical conditions quite different from those that prevailed during the deposition of the auriferous ores. From these considerations and from others arising from a review of the literature of the subject it appears that the genetic relation of the cinnabar deposits to the many gold deposits scattered through the western Nevada quicksilver belt constitutes an interesting problem for future research.

[1] Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, pp. 46, 71, 1909.

[2] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, p. 113, 1909.

[3] Ransome, F. L., Geology and ore deposits of the Bullfrog district, Nevada: U. S. Geol. Survey Bull. 407, p. 103, 1910.

IRON ORE IN CASS, MARION, MORRIS, AND CHEROKEE COUNTIES, TEXAS.

By Ernest F. Burchard.

INTRODUCTION.

In response to many requests received by the Geological Survey during the last three or four years for published data concerning the iron-ore deposits of northeastern Texas, it was directed that a reconnaissance of this area be made in the fiscal year 1914–15. Accordingly the writer spent four weeks in northeastern Texas in the autumn of 1914, a most opportune time, for the results of extensive prospecting were then open for inspection. The following notes on the ore field and its development are presented in the hope that, together with the literature listed at the end of the paper, they may furnish the essential facts concerning several of the most favorably situated of the promising deposits. The reports by Dumble, Kennedy, Penrose, and others of the early Texas Survey (1890–1892) contain a mass of data concerning outcroppings of ore in 20 or more counties, but as they are not illustrated by detailed county maps the value of much of the text is considerably lessened. Moreover, these early investigations were made before systematic prospecting of the concretionary ores had been carried on, and little was known as to their vertical extent and the unoxidized iron carbonate. The laminated ore bed of Cherokee County was better known, because it had been opened by mining in several places.

Two brief examinations of the iron ores in this field had already been made by the United States Geological Survey. The first was a reconnaissance of the stratigraphy and the iron-ore deposits by Lawrence C. Johnson[1] in 1886–1888, and the second was a rapid reconnaissance of the northeastern part of the ore district by E. C. Eckel[2] in 1914. Johnson's report does not consider the economic features of the iron-bearing deposits. Of his own work Eckel says:

[1] Johnson, L. C., The iron regions of northern Louisiana and eastern Texas: 50th Cong., 1st sess., House Ex. Doc. 195, 1888.

[2] Eckel, E. C., Iron ores of northeastern Texas: U. S. Geol. Survey Bull. 260, pp. 348–354, 1905.

"Two ends were in view—a brief report on the present condition and future prospects of the iron industry and an examination of the district with a view to selecting areas for more detailed work." The report was brief, it described conditions at comparatively few localities, and its conclusions with regard to future prospects of the iron industry might now be regarded as conservative in the light of the results of recent prospecting.

The present paper is essentially a preliminary report, but it is hoped that a more comprehensive study of the ore deposits may be taken up in the near future. The Survey will therefore appreciate the receipt from interested citizens of any additional data that may be obtained by prospecting in this field.

The work of the University of Texas Bureau of Economic Geology and Technology on the iron ores of northeastern Texas in 1910 to 1914, under the direction of William B. Phillips, has comprised the publication of a general map of the iron-ore fields, the summarizing of ore analyses and other data of the early Texas Survey, published mainly in papers devoted to the iron trade, the examination of certain of the important ore deposits, and studies of methods for the concentration of the ores.

The writer is under obligations to Dr. Phillips for valuable data placed at his disposal. Others to whom special acknowledgments are due are Prof. Alexander Deussen, of the University of Texas; Col. L. P. Featherstone, of Longview, Tex., president of the East Texas Brown Ore Development Co.; and H. A. O'Neal, vice president, E. E. Vaughan, general manager, and J. J. Skinner, chemist, of the Texas Iron Association, Atlanta, Tex.

LOCATION AND EXTENT OF ORE FIELD.

The iron-ore district of northeastern Texas lies between parallels 31° 30′ and 33° 30′ N. and meridians 94° and 96° W. and measures roughly about 135 miles from north to south and 110 miles from east to west. (See fig. 3.) Deposits characterized as brown iron ore have been noted by the Texas Geological Survey in the following 21 counties within this area: Anderson, Camp, Cass, Cherokee, Gregg, Harrison, Henderson, Hopkins, Houston, Marion, Morris, Nacogdoches, Panola, Rusk, Sabine, San Augustine, Shelby, Smith, Upshur, Van Zandt, and Wood. The distribution of these ores, with the exception of certain deposits in Camp, Hopkins, and Upshur counties, is shown in a general way on Plate IV of the Second Annual Report of the Texas Geological Survey, published in 1890. A later map, showing the same ore deposits with minor additions and including also the lignite outcrops and mines, blast furnaces, and producing oil fields, was published in 1912 by William B. Phillips, director of the University of Texas Bureau of Economic Geology

and Technology. South and southwest of this area isolated deposits of brown ore have been noted in several counties, one of considerable extent in Gonzales County having been recently visited by Dr. Phillips.[1]

LIST OF ORE-BEARING TRACTS

1 Bowie Hill	5 Pruitt	9 Lasater	13 State mine
2 Waters	6 Harris	10 Gilbert	14 State mine
3 Bivins	7 Jernigan	11 Norwood	15 Star and Crescent
4 Surratt	8 Orr	12 Veal's	16 Tassie Belle

FIGURE 3.—Outline map of the northeastern Texas iron-ore district. Geology by Alexander Deussen, with additions by E. F. Burchard.

[1] Personal communication, December, 1914.

Topographic maps of the Daingerfield, Linden, and Atlanta 15-minute quadrangles, all in the northern part of the iron-ore field, have been issued by the United States Geological Survey. The New Boston and Texarkana 15-minute quadrangles, in the next tier north, have also been mapped, but they lie beyond the area of the ore field. These maps are printed on a scale of 1:62500, or about 1 mile to 1 inch, with 20-foot contour intervals. The price of each map is 10 cents.

THE IRON ORE.

TOPOGRAPHIC RELATIONS.

The surface of northeastern Texas is a plateau, 450 to 600 feet above sea level, that has been moderately dissected by erosion to depths of 200 to 400 feet. Much of the surface is gently rolling, with shallow stream valleys, but the highest portions of the former plateau are now flat-topped ridges with steep slopes incised by sharp ravines. These flat-topped ridges are generally narrow and crooked and have many spurs or branches. In places, however, they widen out into level areas a mile or more in width. These high level areas are particularly well developed in Cherokee County. They have persisted because of the greater resistance to erosion offered by certain beds of hard sandstone and limonite with which they are capped.

GEOLOGIC RELATIONS.

In the iron-ore district of northeastern Texas the surface rock formations consist chiefly of sand, clay, gravel, and silt, varying greatly in their degree of induration but predominantly soft or little consolidated. The most recent deposits—those that form the bars, flood plains, and terraces of streams—are of Quaternary age, but the great masses of sand and clay with which the iron-ore deposits are associated are of early Tertiary age (Eocene).

The two Eocene formations which contain the principal deposits of brown ore are termed the Mount Selman formation and the Cook Mountain formation. These formations constitute the lower two-thirds of the Claiborne group. They overlie the Wilcox formation, which is also widespread in the area, and to the south they underlie the Yegua formation, the topmost formation of the Claiborne group. The most recent outline of the stratigraphy of eastern Texas is that given by Deussen,[1] whose paper is illustrated by a geologic map that groups together the Mount Selman and Cook Mountain formations, but in more detailed mapping it may be possible to differentiate the two formations. It has been determined that of the

[1] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, pp. 26–83, 1914.

deposits discussed in this paper those of the northern counties, Cass, Morris, Marion, and Upshur, are comprised in the Mount Selman formation, and those near Rusk, Cherokee County, in the Cook Mountain formation. The occurrence of the northern deposits in the lower rocks is due to the fact that the strata have a slight dip in a south-southeasterly direction, so that the surface bevels the edges of the rocks, exposing the older formations progressively northward and northwestward.

A succinct description of the surface formations in this iron-ore district can best be given by adapting those portions of Deussen's outline of the Cenozoic deposits of the Texas Coastal Plain[1] which relate to the area.

Outline of geologic formations in northeastern Texas brown-ore district.

System.	Series.	Group and formation.		Thickness.	Lithology.
				Feet.	
Quaternary	Recent.			0–50	Fluviatile deposits, consisting of brown, red, or black sandy clay or silt of the low overflow terraces of the streams; also present flood-plain materials, including sand and gravel bars.
Erosion interval.					
Tertiary.	Eocene.	Claiborne group.	Cook Mountain formation.	400	Palustrine and marine deposits, consisting of lenticular masses of yellow sand and clay; in places, lenses of green calcareous, glauconitic, fossiliferous marl. Beds of limonite and lignite. Some of the clays carry fossiliferous calcareous concretions. Formation as a whole is decidedly ferruginous.
			Mount Selman formation.	350	Palustrine and marine deposits, consisting of red, ferruginous indurated and probably altered green sand, with casts of shells, lenses of lignite and clay, and beds and concretions of limonite. The formation as a whole is conspicuously ferruginous.
		Wilcox formation.			Palustrine, marine, and littoral deposits. Does not carry ferruginous deposits of importance.

The Wilcox formation, which is the oldest one exposed in the brown-ore district, occupies portions of Anderson, Henderson, Van Zandt, Smith, Gregg, Wood, Hopkins, Titus, Camp, Upshur, Cherokee, Rusk, Marion, Harrison, Panola, Shelby, Nacogdoches, San Augustine, and Saline counties. It does not carry ferruginous deposits of economic importance.

The Mount Selman formation is exposed in parts of Anderson, Henderson, Cherokee, Rusk, Gregg, Harrison, Marion, Morris, and Cass counties. The Cook Mountain formation is exposed in Houston, Anderson, Cherokee, Nacogdoches, San Augustin, and Sabine counties. As indicated in the outline above, the Mount Selman and

[1] Deussen, Alexander, op. cit., pp. 27–29.

Cook Mountain formations are lithologically similar, although the Cook Mountain may carry more clay. The deposits of brown ore referred provisionally to these two formations differ in certain important respects, as will be shown in this paper.

All the deposits of iron ore, including both limonite and iron carbonate, so far as observed by the writer, are associated with glauconitic sand. Where the sand is more sparingly glauconitic the deposits are leaner in iron, and in beds that are composed only of silica sand no ferruginous deposits that could be termed iron ore are found. Iron pyrite has been observed in the unoxidized zone, but in relatively minute quantities, and to it can not be ascribed so important a part in the genesis of the ore as is evidently played by glauconite. The proximate source of the iron is believed to be the ferruginous sands and clays that inclose the ores, but it is probable that the ores themselves assumed their present form after the Claiborne sediments were deposited and had become a land area. All the ore material may have passed through the carbonate stage before becoming oxidized, but there is evidence that some of the limonite deposits near the surface are migrating downward through solution and redeposition.

CHARACTER.

Mineralogy.—The ore consists chiefly of limonite, or hydrated sesquioxide of iron ($2Fe_2O_3.3H_2O$), but it includes other hydrated oxides of iron and is popularly termed brown ore. There are, however, many deposits of limonite which are found to grade into iron carbonate ($FeCO_3$) of varying degrees of purity below the oxidized or weathered zone. The brown ore and the carbonate ore both contain more or less silica and alumina and other impurities, as indicated in the chemical analyses. (See pp. 86, 88, 90, 94, 96, 97.)

Form of deposits.—Both the brown ore and the iron carbonate occur in nodular and geodal forms segregated in glauconitic sand and clay in thin lenses and irregular ledges, and also as more or less honeycombed thin sheets and layers, fine fragments, crusts, small isolated nodules, and irregular masses of almost endless variety. Unconsolidated material, residual from the breaking down of such masses, is found in many places at the surface. The brown ore occurs also, particularly in central Cherokee County, in a rather persistent laminated bed, 1½ to 4 feet thick, near the top of the highest table-land. Another common form of ferruginous deposit is the conglomerate that crops out on the sides of many stream valleys and is even in process of formation in certain stream beds to-day. This conglomerate occurs as local lenses composed of pebbles of sandstone, which is more or less ferruginous itself, pebbles of limonite, and locally a few white quartz pebbles and angular fragments of silicified wood,

the whole being cemented together by limonite. Bowlders of this conglomerate reach thicknesses of more than 2 feet in places, but it can not be considered as an iron ore.

The principal forms of the iron-ore deposits may thus be summarized as (1) residual, unconsolidated deposits of limonite; (2) nodular, geodal, and concretionary masses of limonite and iron carbonate; (3) laminated beds of limonite.

DISTRIBUTION OF DEPOSITS.

Ferruginous deposits such as are described above are characteristic of the Mount Selman and Cook Mountain formations wherever they are exposed in the 21 counties of northeastern Texas heretofore enumerated, but in only 6 or 7 of these counties have the deposits appeared of sufficient promise to warrant prospecting or development. Foremost among the counties that contain promising deposits of brown ore are Cass, Morris, Marion, and Cherokee, which are discussed in this paper. Other counties that may be considered as having deposits of possible future value are Upshur, Harrison, Anderson, and Henderson. All these counties were visited by the writer during the recent reconnaissance, and particular inquiry was made regarding possible areas in other counties, such as are indicated by the Texas State maps, but in view of the information obtained and the short time available it was not considered important to extend the reconnaissance farther at that time. There are, doubtless, within certain remaining counties, not visited by the writer, many deposits of brown ore which might be worthy of development if they were situated adjacent to a railroad but which do not warrant the construction of a single mile of spur track and from which it will not pay at present to haul ore by wagons.

DEPOSITS IN CASS COUNTY.

BOWIE HILL.

Some of the most important deposits of brown ore in Texas are within Cass County, but here, as elsewhere, the deposits are widely separated. Certain of these deposits are within the Atlanta 15-minute quadrangle, mapped by the United States Geological Survey. One of the best known of these deposits is on Bowie Hill, about 7 miles due north of Atlanta and 2 miles west of the Texas & Pacific Railway (fig. 3, No. 1). Bowie Hill is a flat-topped wooded ridge, 1¾ miles long, the highest part of which is about 200 feet above the bayous in the surrounding country, or 460 feet above sea level. The hill has resisted erosion more successfully than neighboring areas, on account of a cap of ferruginous beds above the 400-foot level.

The brown ore on Bowie Hill is found in the top 15 to 35 feet of the highest land on the hill. A generalized section from many test pits and prospect trenches is as follows:

Generalized section of ore-bearing beds on Bowie Hill.

	Feet.
Residual fragments of limonite in top soil, in places practically solid ore gravel	1–3
Ledge of nodular limonite, more or less solid	½–1¼
Scales and thin bands of limonite, with a few thicker layers or ledges interlaminated with glauconitic sandy layers. The limonite in this condition ranges from pieces of the thickness of small chips up to masses 1½ feet thick and is scattered through yellowish to red sand and clay. It occurs in overlapping, roughly lenticular streaks, or broken and discontinuous seams. The limonite constitutes, in the sections observed, 20 to 30 per cent, by volume, of the dirt. Thickness of limonitic sand and clay	12–15
Iron carbonate in nodular masses from the diameter of an acorn up to 6 inches, or in thin irregular lenses, embedded or interstratified in glauconitic sand and greenish-black clay called "buckfat" clay. The iron carbonate is in general partly altered to limonite or to reddish hydrated oxides of iron, which form a scale or crust of varying thickness around the carbonate nucleus and along cracks which intersect the masses. Thickness of exposed portions of the unoxidized beds	1–5

A section of the upper portion of the ore-bearing ground measures in detail as follows:

Section of cut at east end of washer trestle, Bowie Hill.

	Ft.	In.
1. Soil, roots, and limonite débris	1–6	
2. Limonite in layers 1 inch to 4 inches thick		8–12
3. Reddish-yellow sand, in part glauconitic		9–15
4. Limonite ledge with wavy and crumpled layers		6–15
5. Yellowish-red glauconitic sand with ocherous nodules and flakes		½–11
6. Limonite ledge with wavy and crumpled layers interstratified with a little yellowish clay and glauconitic sand. (Nos. 4 and 6 come together, No. 5 forming a wedge between)		1–5
7. Reddish clay and yellow sand, mostly glauconitic, with ocherous nodules and lenses	1	1–3
8. Limonite in ½-inch to 2-inch bands, interstratified with glauconitic sand and running into ocher		2–3
9. Yellow glauconitic sand, with small ocherous lenses		10
10. Limonite streak running into ocher		¼–1
11. Yellow glauconitic sand		3
12. Ocherous clay		1
13. Yellow glauconitic sand		4

	Ft.	In.
14. Limonite ledge, with slightly wavy laminæ containing thin seams of ocher and glauconitic sand	1	9
15. Yellow sand, not glauconitic		1
16. Limonite ledge, base concealed		1

Other members besides No. 5 of this section are more or less wedge shaped as exposed, and the great variability in thickness and extent of all the brown-ore members is easily demonstrated by the use of a pick, and is shown in the following two sections, displayed 35 feet apart in the same trench:

Section at face of trench south of wagon road, Bowie Hill.

	Ft.	In.
Soil and brown-ore débris	2	4
Reddish sand		8
Limonite		6–11
Reddish sand		10–14
Limonite		2½–6
Reddish glauconitic sand with light clay streaks		20–24
Limonite		2–6
Reddish glauconitic sand with four thin crusts of limonite	1	1
Reddish glauconitic sand with light clay streaks	1	3
Limonite		4
White and yellow clay and glauconitic sand		3–4
Limonite		3–4
White clay and yellow glauconitic sand	1	0
Limonite		4–6
Reddish-yellow glauconitic sand	1	3
Reddish clay, becoming greenish black at base		6–7
Iron carbonate, concretionary layer		6
Base concealed by water.		

Section at side of trench south of wagon road, Bowie Hill.

	Ft.	In.
Soil and limonite débris	2	1
Limonite layer, broken and interstratified with glauconitic sand and clay		7
Reddish clay and glauconitic sand containing limonite fragments	1	6
Limonite streaks and crusts in glauconitic sand and clay (about 25 per cent limonite)	2	6
Yellow glauconitic sand with white clay streaks	1	4
Limonite, in wavy and honeycombed layer		6
White to reddish clay		7
Limonite, in irregular seam		1–2
White to reddish clay with limonite fragments		5–8
Limonite		11
Yellow glauconitic sand		7
Ocherous sand		1
Yellow glauconitic sand		3
Limonite and ocherous sand		2–3

	Ft.	In.
Yellow glauconitic sand and ocherous nodules	1	0
Limonite		$\frac{1}{4}$–$1\frac{1}{2}$
White clay		1
Yellow glauconitic sand with white clay streaks and a little limonite		7
Base concealed by water.		

The old Sulphur Fork iron furnace was built near Bowie Hill, west of Springdale, in 1864, and operated until April, 1865.

There are other small knobs and narrow ridges within a radius of 2 miles of Bowie Hill on which small residues of ferruginous material are present, but probably not in large enough areas to be worked independently.

NORTHWEST OF ATLANTA.

Two deposits of brown ore were noted northwest of Atlanta, one about 2 miles and the second about 6 miles from the town and about 1 mile southeast of Anti School (fig. 3, No. 2). In the first-named area there are good surface showings of ore, but little prospecting has been done. In the other area, which is known as the Waters tract, the surface above the 400-foot contour appears to be covered by a concentrated deposit of loose residual brown ore, in places 1 foot to 2 feet thick, ranging from fine gravel to 6-inch lumps mixed with some dirt. Here a number of prospect pits 6 to 35 feet in depth have disclosed a promising though small area of ore. The distance to the Texas & Pacific Railway at Queen City is 5 miles in an air line.

NEAR BIVINS.

The next and last fairly large area of brown ore within the Atlanta quadrangle lies $5\frac{1}{2}$ to $7\frac{1}{2}$ miles southwest of Atlanta and 1 to 3 miles northwest of the Texas & Pacific Railway at Bivins (fig. 3, No. 3). The ore-bearing area occupies the upper part of a branching wooded ridge and lies generally above the 360-foot level. Some mining of concretionary limonite near the surface was carried on in former years to supply the blast furnace at Jefferson, Tex. Only lump ore was taken, and the dumps contain much ore that might pay to wash. This area has been prospected by numerous shallow test pits, most of which show good ore in a ledge 6 to 8 inches thick near the surface and some of which show two or three more ledges below, besides thinner seams and crusts. Most of the pits here are not more than 8 feet deep and are too shallow to demonstrate the presence of ore at levels comparable with certain other tracts of ore land in Cass County, but it is reported that this area is to be prospected deeper with the Keystone drill.

The limonite near Bivins is associated with oxidized glauconitic sand, but this sand appears to be leaner in glauconitic oolites and to

include a larger proportion of silica sand than that of certain areas that have been demonstrated to contain rich ore. Two deep prospect pits showed at the bottom iron carbonate in concretionary and lenticular forms.

NORTH OF LINDEN.

In the Linden quadrangle, which adjoins the Atlanta quadrangle on the west, there are several areas of brown ore, one of the largest of which occupies the wooded table-land in the vicinity of Central Grove School, 4 to 5½ miles north of Linden (fig. 3, No. 4). This area, known locally as the Surratt tract, is cut by the headwaters of Bowman Creek, along the lateral slopes of which limonite crops out in heavy ledges, generally 1 foot or more thick, and there is also much débris scattered over the slopes. The general altitude of the

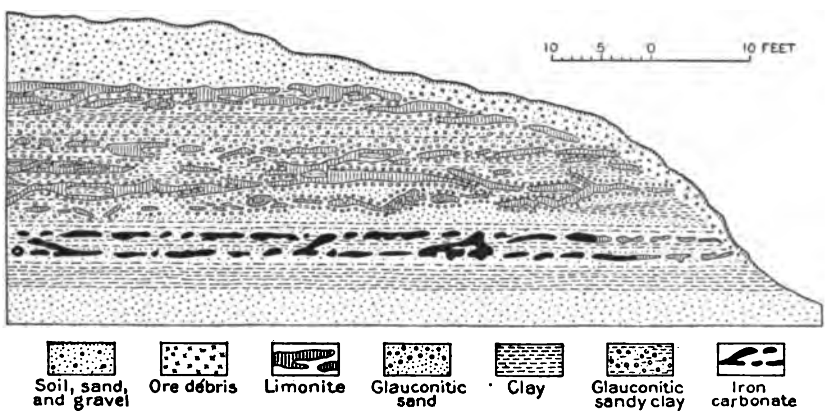


FIGURE 4.—Section showing associations of iron ore in trench from edge of hill on Surratt tract, north of Linden, Cass County, Tex.

top ledge is about 410 feet, and below this for 35 feet or more fragments and layers of limonite a quarter of an inch to 3 or 4 inches thick are found scattered throughout the sand and clay. Two prospect trenches on both the east and west sides of Bowman Creek show clearly the relations of the limonite, glauconitic sand, and clay and the fairly sharp line of demarcation between the oxidized zone, containing limonite and yellowish to reddish glauconitic sand, and the unoxidized zone, containing iron carbonate and green glauconitic sand and greenish clay, or "buckfat." This unweathered zone does not anywhere extend to the face of the hill but is roughly parallel to the surface, at 15 to 30 feet from it, except below ground-water level. The area has been prospected also by many test pits and some drill holes. On the pine-forested upland, which is surfaced by light-colored sand, there is little or no suggestion of limonite below, yet good showings are obtained in most of the prospects. (See fig. 4.)

The following section of the trench on the east side of Bowman Creek, near the experimental concentrating plant, is typical of the beds in this vicinity, except that the top ore ledge is not well represented.

Section of prospect trench on Bowman Creek 4½ miles north of Linden.

	Ft.	In.
Top soil and sand, with lumps of indurated glauconitic sand	2	3
Nodules of limonite		3
Sand and clay		2
Limonite		2-4
Reddish clay and glauconitic sand		10
Ore-bearing material, consisting of glauconitic sand with a little red clay. Contains 20 or more thin seams of limonite, ¼ to ½ inch thick. These seams lie practically flat. Some of them are sandy, and many are coated with layers of glauconitic sand, part of which may be separated by washing. Some of the glauconitic sand is indurated in thin seams	4	10
Glauconitic sand and white to yellow clay	1	0
Limonite		3
Glauconitic sand and white to yellow clay		8
Limonite		2
Glauconitic sand and white to yellow clay		3
Limonite		3-4
Glauconitic sand with fragments of limonite	2	6
Limonite		3
Glauconitic sand		3
Limonite		2½
Glauconitic sand	1	3
Limonite mixed with sand		7
Glauconitic sand with 18 to 20 streaks of ocherous limonite	8	4
Iron carbonate altered to limonite on top. The carbonate ore contains flakes of lignite		5
(A shaft has been dug below the level of the trench at this point and is reported to show yellow to greenish glauconitic sand and iron carbonate down for a depth of 36 feet.)		
Reddish-yellow glauconitic sand with a little red clay and much limonite in broken seams, fragments, and isolated nodules. This material has been estimated as capable of yielding 25 to 30 per cent by volume of limonite	10	6
(Here the section begins 50 feet nearer the slope of the hill, in oxidized material again.)		
Greenish-white clay with a few streaks of glauconitic sand and a little limonite. The lowest seam of limonite is 1 to 3 inches thick and appears to be the base of the ore-bearing material	4	4
White to yellowish fine sand containing a little clay	5	0

There are several areas of brown ore in the Linden quadrangle that may be noted in passing along the ridge roads between Linden and Central Grove School and between Linden and Atlanta, and there is some ore-bearing land in the immediate vicinity of Linden, but all these are relatively unimportant owing to their slight extent. In the southwest corner of the quadrangle, between Flat Creek and Concord School, a series of knobs extending northwest for a distance of about 2 miles reach an altitude of more than 400 feet and are reported to carry valuable deposits of brown ore.

SOUTHEAST OF LINDEN.

In the part of Cass County south of the Linden and Atlanta quadrangles, which has not yet been topographically mapped, there are several ore-bearing areas. One area that is being actively prospected by trenches, pits, and drill holes lies about 5 miles southeast of Linden and is known locally as the Pruitt tract (fig. 3, No. 5). In this tract the best showings of ore appear to be around the edges of the upland, where gullies have exposed it, although some of the pits have shown good ore-bearing material below the cotton fields that occupy the highest levels. Below these fields the ore is covered by 6 to 10 feet of light-gray sand mixed with a little clay. The following section is typical of the best showing of ore-bearing material in this vicinity:

Section in prospect trench 5½ miles southeast of Linden.

	Ft.	In.
Soil, sand, and limonite débris	2	6
Limonite, in thin plates		6–8
Reddish-yellow (oxidized) glauconitic sand	3	0
Limonite		10
Clay and reddish-yellow glauconitic sand		3
Limonite		1½
Grayish-white clay		3
Reddish-yellow glauconitic sand		9
Limonite		4–6
Reddish-yellow glauconitic sand		6
Limonite		½
Reddish-yellow glauconitic sand		2½
Limonite and oxidized glauconitic sand		7
Greenish-black (unoxidized) clay, or "buckfat"		11
Greenish (unoxidized) glauconitic sand		4
Iron carbonate, nodular ledge		4
"Buckfat" clay		4
Iron carbonate, nodules		3
"Buckfat" clay, base not exposed.		

This trench is cut about 120 feet into the north hillside facing a small creek. The altitude of the base of the trench is about 290

feet. On the opposite side of the creek a similar trench has been dug, showing possibly a slightly higher proportion of limonite and an equally sharp demarcation between the oxidized zone, containing limonite in reddish-yellow glauconitic sand and clay, and the unoxidized zone, containing iron carbonate associated with green glauconitic sand and greenish-black ("buckfat") clay.

The section given in detail above shows about 3 feet 6 inches of ore in a total of about 12 feet 6 inches of sediments. This corresponds to about 28 per cent of ore by volume, and perhaps 40 per cent by weight.

From 8 to 9 miles southeast of Linden and 1½ to 2 miles northwest of the Texas & Pacific Railway, an extensive limonite-bearing area has been prospected by two or more iron-ore companies that have holdings there. The ore is found on the high divides and tablelands. As shown by the trenches, some places are nearly barren, but in others there is a richer concentration of iron ore than has been seen by the writer elsewhere in northeastern Texas. This area contains the properties locally known as the Harris and Jernigan tracts (fig. 3, Nos. 6 and 7).

The following section, shown in a shallow trench about 125 feet long where brown ore was formerly mined for use in the blast furnace at Jefferson, illustrates one phase of the occurrence of ore in this vicinity:

Section in old mine trench 8½ miles southeast of Linden.

	Ft.	in.
Soil and residual limonite, mostly in kidney-shaped concretions	2	2
Reddish cross-bedded glauconitic sand		9
Limonite in crusts and concretions		3
Reddish glauconitic sand with streaks of white clay and a few concretions of limonite		8–10
Limonite		1–2
Reddish glauconitic sand and white clay		7
Limonite		2–3
Reddish glauconitic sand and white clay		5
Limonite		1½
Yellow ocherous silica sand, base concealed		4

The concretionary ore at the top is rich and is reported to have been in great demand when the blast furnace was in operation.

An unusually large prospect trench has been excavated in this tract a short distance southeast of the old mine trench. This large trench is 6 to 7 feet wide, about 14 feet deep, and 130 feet long and connects with a narrower trench at right angles, which extends for 50 to 60 feet, to the brow of the hill and affords drainage for the large trench. In addition to the material taken from the trench a block of the top ore-bearing ground about 50 feet square has been

removed from one side of the trench, and the ore from the whole excavation has been stored in a large pile in a neighboring field. The following section indicates the character of the ore displayed in the large trench. The top 7 feet is especially rich in ore.

Section in large trench 9 miles southeast of Linden.

	Ft.	In.
Soil rich in ore débris	1	0
Ledge of limonite with a few seams of sand	4	10
Glauconitic sand and clay		7–10
Limonite, in part concretionary		3–8
Light-yellowish to reddish glauconitic sand		3
Limonite, in part concretionary		4–7
Reddish glauconitic sand and white clay, with a few small nodules of limonite; the sand is partly indurated by ferruginous streaks	1	9
Limonite		2–3
White and reddish glauconitic sand	1	11
Limonite lens, 3 feet long in sand layer		4
Limonite, with seams of indurated sand		10
Bluish-green clayey sand		3
Base concealed; iron carbonate reported below.		

The section outlined above thus shows about 8 feet of ore in 13 feet of sediments. A photograph of this prospect trench has been published.[1]

In contrast with the rich section just given is the following section, shown at the face of a cut about 200 yards east of the large trench:

Section in prospect trench 9 miles southeast of Linden.

	Ft.	In.
Sand, light colored, mostly silica	1	6
Limonite		14–18
Reddish glauconitic sand, with white clay streaks and five streaks of limonite, ¼ to ½ inch thick	1	6
Limonite, with streaks of sand		4–5
Reddish glauconitic sand, cross-bedded, containing white streaks	1	11
Limonite		7
Yellowish sand		5
Limonite		2
Yellowish sand, cross-bedded		10
Limonite		4
Reddish glauconitic sand, cross-bedded, containing white clay streaks	3	7
Limonite		3
Reddish glauconitic sand, cross-bedded, containing white clay streaks	3	6

[1] Linton, Robert, Texas iron-ore deposits: Eng. and Min. Jour., Dec. 20, 1913, p. 1153.

According to this section there are about 3 feet 2 inches of limonite within 16 feet 3 inches of sediments.

In this area one prospect trench has been cut entirely through a small hill and affords a view of the iron-bearing sediments for a distance of about 350 feet and to a depth of 10 to 20 feet. The richest ore-bearing material in this trench appears to be just about the middle of the hill. The following two sections were measured in this trench:

Section in southeast portion of trench cut through hill 9 miles southeast of Linden.

	Ft.	in.
1. Soil and limonite débris		6
2. Limonite	1	7
3. Sand and limonite alternating in thin seams		7
4. Reddish-yellow glauconitic sand, cross-bedded, containing white clay streaks	1	11
5. Limonite		3
6. Sand, similar to No. 4		3
7. Limonite		4
8. Sand, similar to No. 4	1	5
9. Clay		2
10. Limonite		3
11. Sand, similar to No. 4		2½
12. Limonite		9
13. Sand, similar to No. 4		8
14. Limonite		1–2
15. Sand, similar to No. 4	1	6
16. Limonite		1
17. Sand, similar to No. 4		10
18. Sand, similar to No. 4, containing two seams of limonite, each about 2 inches thick	10	0

Section near middle of trench cut through hill 9 miles southeast of Linden.

	Ft.	in.
Soil and limonite débris		18–26
Limonite, in heavy ledge with lenses and "pots" of sand and clay	6	3
Yellow glauconitic sand, locally indurated, containing a few seams of limonite	3	4

The southwestern portion of this area, known locally in part as Jernigan Hill, has also been tested extensively by prospect pits from 9 to 44 feet deep. Some ore was found in nearly all the pits that were noted. Some of the top ore is too sandy to be of commercial value, but there is much good concretionary and nodular ore. There is generally a heavy ledge of limonite near the surface, irrespective of a difference in elevation of 25 to 30 feet, a fact which suggests a downward concentration, not only of the residual ore accompanying the degradation of the hill but also of iron hydroxide, thus continu-

ing to build up ledges of ore a foot or two beneath the surface. Forest fires have partly dehydrated much of the surface ore, altering its color to a dark red. An ore seam 8 inches thick has been found at a depth of 45 feet below the highest part of the ridge.

The last portion of this area to be visited lies north of Jernigan Hill and is known as Nigger Hill. The test pits here range generally from 6 to 10 feet in depth, but a few are 18 feet deep. A well being dug for water encountered only fragments of ore but cut through some pyritiferous green sandstone and dark clay at a depth of 40 feet. The ore shown by the shallow pits consists largely of rather rich "kidney" concretions, but some portions are sandy. Ferruginous conglomerate containing quartz sand, rounded quartz pebbles, and angular fragments of silicified wood was noted on the surface.

NEAR LASATER.

In the southwestern part of Cass County, on the north side of the Missouri, Kansas & Texas Railway between Avinger and Lasater stations, is an area of brown ore that was formerly worked in several places to supply ore to the furnace at Jefferson. The railway cut at Avinger shows limonite in a thin ledge near the top, associated with reddish glauconitic sand; at the base is exposed bluish, unoxidized clay containing a few nodules of iron carbonate. Near Orr switch, at the south edge of the county, a ledge of limonite has been mined on the sides of the valley of a small creek, about a quarter of a mile northeast of the railway (fig. 3, No. 8). The ledge is generally 1 foot 4 inches to 2 feet thick, but attains in one place an exceptional thickness of 6 feet 6 inches in three reefs, separated by two lenses of glauconitic sand 4 inches to 1 foot 4 inches thick. At this place the ledge crops out at the surface, but where the ledge is thinner there are generally 2 to 3 feet of soil and loose ore débris above it. This ledge of limonite may be traced down the hill nearly to creek level. The ore is in rounded nodular masses, coalescing so as to form a ledge. Some of the ore is sandy and contains layers and coatings of glauconitic sand, but most of the ledge is limonite of good quality. It has been mined by pick and shovel along the outcrop in two or three places for a few hundred feet each. What is apparently the equivalent of this ledge has been mined at the top of the hill about a quarter of a mile southeast of the creek and about the same distance from the railway. Here a shallow trench extends around the crest of the hill and exposes ore generally from 1 foot to 1 foot 6 inches in thickness.

Two small iron furnaces were operated in early days in southwestern Cass County. The Nash furnace was erected within a few miles of Avinger several years prior to 1859, and is believed to have

been the first furnace to utilize the brown iron ore of eastern Texas. The other furnace, known as the Hughes, was built about 1861 and was operated during the Civil War. It was 1½ miles southeast of Hughes Springs.

ANALYSES.

Many chemical analyses of the brown iron ores in Cass County have been published by the Geological Survey of Texas and by technical magazines. Analyses of the carbonate ore are not so readily available, probably because only recently has this type of ore been reached in prospecting. The analyses by the Texas Survey were evidently made on good average prospect samples rather than on picked samples of ore. Occasionally a sample was found in which the silica proved to be so high and the iron so low that the material could not be classed as an ore according to present standards. In making use of these data such analyses have not been included.

The following analyses indicate the composition of certain types of the deposits:

Analyses of Cass County iron ores.

	1	2	3	4	5
Silica (SiO_2)	10.96	20.25	37.86	2.50	1.10
Alumina (Al_2O_3)	3.51	12.91		2.10	1.02
Lime (CaO)					.16
Phosphorus (P)	.118	.149		.043	.05
Sulphur (S)	.124	.132		.096	.05
Loss on ignition (mostly combined water)	9.62	12.25			{ [a] .15 [b] 1.05
Carbon dioxide (CO_2)					36.54
Manganese (Mn)				.20	.10
Titanium dioxide (TiO_2)					.04
Metallic iron (Fe)	49.61	37.41	34.26	48.10	46.44

[a] Water driven off below 100° C.
[b] Water driven off above 100° C.

1. Average of 22 analyses of nodular and concretionary limonite. Kennedy, William, Report on the iron-ore district of east Texas: Texas Geol. Survey Second Ann. Rept., pp. 79–87, 1891.
2. Average of 5 analyses of laminated limonite. Idem.
3. Average of 8 analyses of ferruginous conglomerate. Idem.
4. Analysis of nearly pure, cleaned carbonate ore. Linton, Robert, Texas iron-ore deposits: Eng. and Min. Jour., Dec. 20, 1913, p. 1156.
5. Analysis of average sample cleaned carbonate ore from vicinity of Linden. Analyst, R. C. Wells, United States Geological Survey, March 15, 1915.

DEPOSITS IN MARION COUNTY.

NEAR LASATER.

A few deposits of brown ore were examined in the northwestern portion of Marion County. Southwest of the Missouri, Kansas & Texas Railway ore has been mined at several places 1 to 2 miles west of Lasater (fig. 3, No. 9). Prospect trenches and old workings in this area show ore from 1 foot 2 inches up to nearly 5 feet thick, but the latter thickness is exceptional and is due to the formation of an unusually thick pocket of ore. Old stock piles of ore show a fair to good grade of limonite, some of which is ocherous and some of

which is incrusted with glauconitic sand. In addition to the ore shipped to Jefferson, Tex., shipments of lump ore are reported to have been made to Birmingham, Ala., about 1908 or 1909. Little or nothing seems to be known as to whether there is ore in small fragments below the top ledge, as the deepest cuts are not more than 5 to 6 feet below the surface.

SOUTHWEST OF AVINGER.

The tract of ore land most recently developed in Marion County, known as the Gilbert tract, is situated in the extreme northwest corner of the county, about 6½ miles southwest of Avinger and 7 miles northeast of Ore City (fig. 3, No. 10). It is tapped by the Port Bolivar Iron Ore Railway, a line extending north from Longview, Tex., a distance of about 30 miles. This road was built to transport ore from this field to Longview and thence over the Texas & Gulf Railway (Atchison, Topeka & Santa Fe system) to Port Bolivar, on Galveston Bay. It is planned eventually to extend the Port Bolivar Iron Ore Railway northward to connect with the Texas & Pacific Railway, probably between Avinger and Hughes Springs. The ore is exposed along the brow of a high, flat-topped wooded ridge, known as 75-Acre Hill. The base of the main ore ledge lies about 80 feet above the railway spur and, according to company maps, is at an altitude of about 370 feet. In open cuts made in 1913 the ore is shown to be concretionary limonite, generally of high grade. In the cut which extends about 500 feet N. 30° W. from a point near the tipple the best ore forms a ledge 8 to 15 inches thick 2 to 4 feet below the surface, and is overlain by sandy ledges of ore and ore débris in the soil. The ledge is concretionary in structure, and some of the ore débris consists of concretions. About a quarter of a mile northwest of the first cut another cut has been made along the brow of the ridge and around the head of a hollow. This cut is about 800 feet long and 3 to 6 feet deep and discloses a ledge of ore that is in places very thick. In one place 5 feet of excellent ore was measured, composed of two concretionary ledges and extending down from the grass roots. At another place a concretionary mass of ore measures 4 feet in thickness. At other places the good ore is only about 1 foot thick, with sandy ore and clay above it.

Aside from the mine cuts, 75-Acre Hill seems to have been fairly well tested by pits and other marginal and surface cuts. A contour map on a scale of 200 feet to 1 inch, with 10-foot contour intervals, has been made, and by its use it has been determined that there is on this hill perhaps 30 acres of ore-bearing land, besides 25 acres carrying float ore. Most of the test pits are shallow and show a moderate quantity of ore, generally not more than 10 to 15 per cent by volume.

Many ferruginous bowlders are scattered about the surface, but these are mostly too sandy to be considered good ore. The contour and surface of the hill resembles that of Bowie Hill, Cass County, in many respects, particularly in the outstretching spurs and reentrant ravines on its borders. On the southeast margin of the hill a machine shop, tipple, and crusher platform have been erected, and an ore chute, or flume, extends down to the railway spur, 85 feet below. The chute evidently was not employed to carry ore, however, during the recent mining, as the product from the mine trenches was hauled down by wagons and dumped on a platform above the railway. Here the ore was shoveled into three chutes which discharge on grizzlies, where it was broken by sledges and fed through chutes into the cars.

Two steamer cargoes, each consisting of several thousand tons of high-grade brown ore, were shipped from this property to the furnaces of the Alan Wood Iron & Steel Co., near Philadelphia, Pa., in the summer of 1913.

An iron forge or furnace was operated many years ago at the base of 75-Acre Hill. The only evidences of its former activities are a few remnants of glassy slag.

ANALYSES.

The following series of analyses, which cover a wide range of samples, show the excellent grade of ores found in northwestern Marion County:

Analyses of Marion County iron ores.

	1	2	3	4	5
Silica (SiO_2)	9.05	4.460	6.135	9.40	9.74
Alumina (Al_2O_3)	3.92	2.377	2.728	1.40	4.78
Lime (CaO)	....	....	....	.07	....
Magnesia (MgO)	....	....	....	Trace.	....
Phosphorus (P)	.089	.100	.090	.099	.18
Sulphur (S)	.146	.103	.092	.067	....
Manganese (Mn)	....	.170	.126	.16	1.22
Loss on ignition	10.37	....	....	11.70	....
Metallic iron (Fe)	53.06	57.450	56.030	53.80	51.21

1. Average of 10 analyses of nodular and concretionary limonite. Kennedy, William, Report on the iron-ore district of east Texas: Texas Geol. Survey Second Ann. Rept., pp. 102-106, 1891.

2, 3. Analyses by A. S. McCreath & Son of two cargo samples of ore from Gilbert tract, discharged at Philadelphia, 1913. Dry basis.

4. Analyses by R. N. Dickman of sample averaged from 30 samples from Gilbert tract.

5. Average of six analyses by Charles Catlett of composite samples of ore from Gilbert tract. Dry basis.

Analyses in columns 2 to 5, inclusive, were placed at the disposal of the Survey by Col. L. P. Featherstone, president of the East Texas Brown Ore Development Co.

DEPOSITS IN MORRIS COUNTY.

NORTHWEST OF DAINGERFIELD.

The iron-ore map published by the University of Texas Bureau of Economic Geology and Technology shows a large iron-bearing area west and northwest of Daingerfield. So far as could be ascertained

by a rapid reconnaissance and inquiries, the showings of ore in this area are limited to streaks of very red soil associated with a thin mantle of residual limonite gravel. This limonite gravel ranges from the size of shot up to the size of walnuts and is high in iron. Pieces of the limonite gravel that are comparatively fresh appear to be fragments of the crusts of geodes. On the crest of the ridge northwest of Daingerfield, which reaches an altitude of more than 600 feet, the rock is mostly ferruginous silica sandstone, containing here and there a streak fairly rich in iron, but on the whole too low in iron ever to be regarded as an ore. Bowlders of glauconitic sandstone, slightly ferruginous in streaks, are also found sparingly on the crest of the ridge.

SOUTHEAST OF DAINGERFIELD.

Near the Morris-Cass county line, within 1½ miles north and south of the Missouri, Kansas & Texas Railway, limonite ledges crop out at about the 500-foot level around the rim of the upland. On the Norwood and other neighboring places (fig. 3, No. 11) some surface mining was done 12 or 13 years ago to supply the blast furnace at Jefferson. Several shallow test pits dug in 1910 show limonite in ledges from 8 inches to 4 feet 4 inches thick, the maximum representing an unusually thick mass. In a water well on the place of John Wallace bowlders of iron carbonate containing glauconitic sand were struck in greenish clay at a depth of about 20 feet, and at a corresponding altitude (510 feet) a ledge of limonite crops out on the north slope of the hill a few hundred yards distant. There is much ore gravel over the surface in this vicinity, and many bowlders of concretionary ore of excellent quality. Some bowlders measure 1 foot 6 inches in diameter.

The Missouri, Kansas & Texas Railway cut at Veals switch, 2¼ miles northwest of Hughes Springs, shows the following section:[1]

Section in railroad cut at Veals switch.

	Ft.	In.
Soil		6–12
Yellow sand and sandstone	3–8	
Iron ore	1	0
Yellow sand		6
Iron ore		6
Sand		4
Iron ore		8
Sand	3–5	
Iron ore		1–2
Gray to chocolate-colored clays	8–10	

[1] Eckel, E. C., The iron ores of northeastern Texas: U. S. Geol. Survey Bull. 260, p. 352, 1905.

Nodules of iron carbonate occur at the ore horizons nearest to the dark-colored clay. In a well adjacent to Hervey's cotton gin at Veals switch masses of iron carbonate were found at a depth of about 40 feet. Limonite seams were also found at intermediate depths, and in places films and crusts of a green fibrous mineral occur in cavities in the limonite. This mineral has been determined by W. T. Schaller, of the United States Geological Survey, to be a hydrous iron phosphate, near dufrenite in composition.

South of the main Daingerfield-Hughes Springs wagon road, a mile or more from Veals switch (fig. 3, No. 12), there is much rich limonite scattered about the surface in bowldery concretions, and numerous shallow prospect trenches have disclosed the presence of a ledge of limonite a few inches to 6 feet thick underlying an area of many acres. Some pits, however, have been put down in barren ground.

ANALYSES.

Averages of series of six and four analyses of mixtures of nodular and concretionary brown ore from the principal deposits in Morris County are given below in columns 1 and 2, respectively:

Analyses of Morris County iron ores.[a]

	1	2
Silica (SiO_2)	8.18	4.86
Alumina (Al_2O_3)	3.46	5.29
Phosphorus (P)	.135	.114
Sulphur (S)	.016	Trace.
Loss on ignition (mostly combined water)	10.04	10.61
Metallic iron (Fe)	51.56	55.25

[a] Kennedy, William, op. cit., pp. 177-179.

DEPOSITS IN CHEROKEE COUNTY.

VICINITY OF RUSK.

The most valuable deposits of brown iron ore in Cherokee County are situated near the tops of the plateaus south of Jacksonville, those in the vicinity of Rusk probably being the most extensive and best known. According to Deussen[1] they are to be regarded as belonging to the Cook Mountain formation, the upper of the two iron-bearing divisions of the Claiborne group. The deposits in the vicinity of Rusk that were examined by the writer are of a type entirely distinct from those of Cass, Marion, and Morris counties, which are regarded as of Mount Selman age. Instead of consisting of irregular, ramifying, and fragmentary masses of more or less

[1] Deussen, Alexander, op. cit., pp. 62-63.

nodular ore distributed through 15 to 30 feet of beds, as in Cass County, the Rusk deposit consists essentially of one solid and fairly continuous bed of limonite with almost no residual concentration of ore above and but little ore in seams and nodules below. The limonite bed near Rusk forms a cap near the top of the flat-topped plateau, at an altitude of about 600 feet, and is overlain by unconsolidated gray sand ranging from 1 foot or 2 feet to 25 or 30 feet in thickness. Over areas comprising several square miles there are undulations in the altitude of the bed reaching a maximum of perhaps 30 feet, but in the absence of an adequate topographic map or of precise levels the altitude can not be accurately determined for any given place.

The ore bed ranges from 7 or 8 inches to 3 and even 4 feet in thickness, but the more common thicknesses are between 1 foot 3 inches and 2 feet 6 inches. At the top of the ore bed, however, is a "sand cap," or layer of more or less ferruginous hard sandstone, from half an inch to 4 inches thick. This sand cap may be split freely from the ore in mining. The ore bed is immediately underlain by a few inches of light-colored clay, below which are layers of sand and soft sandstone, some of which is glauconitic. The upper surface of the sand cap is not smooth but is crossed by shallow furrows extending N. 65°–70° W. The width of these furrows is 2½ to 3½ feet, and the height of the crests above the bottoms of the furrows is generally 2 to 3 inches. The sand cap is thickest on the crests of the furrows, but the furrowed surface is characteristic of the limonite also when stripped of its sand cap, although the furrowing is not so marked. At the base of the ore bed botryoidal and rootlike protuberances of limonite extend down into the underlying clay, so that the basal surface is very irregular and presents a strong contrast to the upper surface. (See fig. 5.)

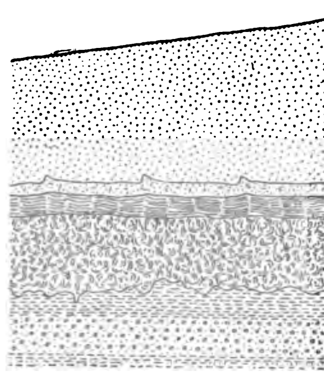


FIGURE 5.—Section of bedded limonite near Rusk, Cherokee County, Tex. Scale, 1 inch equals 5 feet.

The ore itself possesses certain characteristics of texture and color that make it easily distinguishable from the ores of the more northerly counties. The color, for instance, is light brown or buff, several shades lighter than that of the ore of Cass County, except where the

latter is ocherous. The upper 2 to 4 inches of ore generally has fine open laminæ, parallel to the bed, lined with glossy black coatings, with here and there a spot colored bright red. The ore below the laminated layer presents a curly structure when freshly broken, in contrast to the more evenly concretionary type of ore in Cass and Marion counties. The ore with curly structure cracks and crumbles on weathering, and thus is known as "buff crumbly ore." Occasionally a cavity containing sand or sandy clay is found in the ore.

The Rusk ore is considered to carry a relatively high percentage of alumina, and there may be a relation between the presence of this ingredient and the light color of the ore. The ore from the top of the bed containing black-lined laminations is said by furnace men who have had experience in its use to contain a higher percentage of phosphorus than the rest of the ore in the bed.

The ore bed is exposed at a great many places around the rim of the table-land, which forms an irregular crescentic area extending about 3¾ miles northwest and 4¾ miles southeast of the town of Rusk. This area is bordered on the south and west by the Louisiana & Arkansas Railroad, the Texas & New Orleans Railroad extends northward across it from Rusk, and the Texas State Railroad touches its border just north of Rusk. Among the best exposures are those where the ore has been mined, as, for instance, at the several State mines, 3½ miles northwest, 1½ miles north, and 2½ miles northeast of Rusk; at the Star and Crescent mines, 1¾ miles east of Rusk; and at the mines 2¾ miles southeast of Rusk, worked in connection with the Tassie Belle furnace.

The latest and most extensive of the State mines are on the east-west spur of the plateau, beginning about 2½ miles northwest of Rusk (fig. 3, No. 13). These workings, which have been inactive since 1909, consist of open cuts and extend westward for more than 1 mile, interrupted by places where the cover of sand is too thick for stripping and by a ravine where the ore bed has been removed by erosion. An unusually good opportunity was afforded to the writer, in November, 1914, to examine the ore bed at one place where it had been stripped over an area of about 1½ acres. The regular furrowed surface of the ore bed is particularly well displayed in this stripped area, and when viewed from the top of a high bank of sand the surface resembles an abandoned plowed field in which the furrows are still faintly visible. The ore bed ranges in thickness from 15 to 36 inches and probably averages at least 2 feet. Adjoining the tract where the stripped ore bed is still in place piles of lump ore about 4 feet high have been stacked up over an area of about an acre.

In the cut on the Jacksonville wagon road a few thin streaks of brown ore are shown within 15 feet below the ore bed, but they are

of no value and would not warrant mining any of the material below the ore bed.

A smaller abandoned open cut was noted on the rim of the plateau on the west side of the Texas & New Orleans Railroad, about 1 mile north of the State penitentiary, at Rusk. The thickness of the ore ranges from 7 to 16 inches where exposed, and the thickness of the stripping has reached 6 or 7 feet at the maximum. The cover, which is fine gray sand, thickens gradually to the northwest and probably reaches 30 feet at the highest level of the plateau. The ore bed shows a thickness of 2 feet in a railroad cut near by, and a few feet below it are a few thin streaks of limonite, possibly aggregating 5 or 6 inches within 10 feet of sand and soft sandstone, partly glauconitic. The ore was worked here by the State.

Another locality where mining was done by the State is 2 to 2½ miles northeast of Rusk, around the west rim of a northward-extending lobe of the plateau (fig. 3, No. 14). The open cut extends around the edge of the hill for a mile or more, and the stripping was carried to a maximum of 10 feet, but averages much less. The ore bed ranges in thickness from 12 to 30 inches. In places it contains a streak of sand, as is shown in the following section:

Section 2 miles northeast of Rusk.

	Ft.	In.
Sand, fine grained, gray, with soil and grass at top	7	0
Sandstone, hard, with streaks of limonite	1	5
Limonite, compact	1	0
Sand, yellow, soft		5
Limonite, compact	1	3
Clay, white; base not exposed.		

In this section the "sand cap" probably is merged into the ledge of limonitic sandstone above the ore. At other places the typical layer of sandstone, about 2 inches thick, is at the top of the ore. Near the north end of the workings the sand above the ore contains 3 to 4 feet of fairly hard concretionary sandstone, which rendered the work of stripping more difficult. Ore was carried from this place to the State blast furnace by a steam tramroad. The last operations are reported to have been carried on in 1906.

A good exposure of the ore bed was noted on the west margin of the plateau 1¾ miles east of Rusk, at the workings of the Star and Crescent furnace (fig. 3, No. 15), where the last operations are said to have been carried on in 1907. The ore measured 32 to 38 inches in thickness at this place. More ore is still available here, as the cover has not been stripped off to as great a thickness as at the State mines. Ore was trammed down to the blast furnace, a distance of about 1⅓ miles.

The old mines of the Tassie Belle furnace (fig. 3, No. 16) are 1 to 2 miles farther south along the west margin of the plateau, within a short haul of the furnace. These workings have lain idle for about 20 years. In one cut half a mile northeast of the furnace the ore bed is 27 to 29 inches thick and is covered by 3 to 4 feet of sand at the margin of the stripping. A pile of lump ore 1½ to 3 feet high, 50 feet wide, and about 300 feet long has been left here.

ANALYSES.

Averages of seven analyses of laminated brown ore from the bed worked to supply the State blast furnace, and of six analyses of laminated ores from other parts of Cherokee County are given below in columns 1 and 2 respectively.

Analyses of Cherokee County iron ores.[a]

	1	2
Silica (SiO_2)	[b] 19.0	14.08
Alumina (Al_2O_3)	....	10.38
Phosphorus (P)	.175	.062
Sulphur (S)	.020	.440
Water (H_2O)	12.25	8.85
Metallic iron (Fe)	45.68	39.49

[a] Walker, J. B., Reports on the iron-ore district of east Texas: Texas Geol. Survey Second Ann. Rept., p. 291, 1891.
[b] Insoluble.

COMPOSITION OF THE ORES.

In any discussion of the composition of the brown ores of northeastern Texas it must be borne in mind that the three types of ore, nodular, laminated, and conglomerate, show certain essential differences in their average composition, and therefore an attempt to calculate an average composition for all the ores of the area would give results of little or no value to the furnace man. The low percentage of metallic iron and the high percentage of silica in the conglomerate ore, without regard to quantity or accessibility, rule ore of this type out of consideration as a source of ore supply. If the nodular ore and the laminated ore chanced to occur in workable quantities in the same localities, or in localities so close together that both types of ore could be readily assembled and used in a mixed condition in the blast furnace, it might be of interest to average a number of analyses of these two types of ore together. However, as the workable deposits of ore in the counties north of Sabine River are practically all of the nodular or concretionary type and those south of the Sabine are of the laminated type, their geographic separation

renders it improbable that they will ever be mixed to any great extent in the blast furnace, either locally or at eastern iron centers. It is reported that the Texas Iron Co., which leased but did not operate the State furnace at Rusk, planned to utilize a mixture consisting of three parts of Cass County nodular ore and one part of Cherokee County laminated ore. In such mixtures the influence that each type of ore may have on the mixture can be controlled.

A summary of analyses of Texas iron ores[1] has been published recently, from which are taken the following general data, with special data concerning the ores of Cass, Marion, Morris, and Cherokee counties:

In order to make satisfactory replies to the numerous inquiries with respect to the quality of the east Texas iron ores, we have undertaken to examine and classify 207 analyses. Many of them were taken from the report of William Kennedy on "The iron-ore district of east Texas" (Texas Geol. Survey Second Ann. Rept., 1889), which is our chief source of information with respect to these ores up to the time of its publication. This report has long been out of print and copies of it are scarce. In addition, we have had access to many more recent analyses, especially of ores from Cass and Marion counties, where extensive development work during the last two years, particularly that of the Texas Iron & Coal Co., has contributed so much to our knowledge of these ores and of the greatly enlarged area within which excellent material is to be found. * * *

In studying these analyses it was decided to divide them into four groups—for example, from 40 to 45, 45 to 50, 50 to 55, and 55 to 60 per cent of iron. All ores containing less than 40 per cent of iron are disregarded. The time may come when such low-grade material may be used, through processes of crushing, jigging, etc., but we need not concern ourselves with this now. We distinguish, then, four classes of these ores:

Medium, containing from 40 to 45 per cent of iron.
Good, containing from 45 to 50 per cent of iron.
Very good, containing from 50 to 55 per cent of iron.
Extra, containing from 55 to 60 per cent of iron.

It is probably the case that most of the so-called brown ores (and, with the exception of some carbonate ore, all of the east Texas iron ores are of this character) used in this country carry about 45 per cent of iron. It is an exception to the general rule when such ores carry as much as 50 per cent of iron, save when they are calcined, and this practice is not common. Such ores go direct from the washers to the stockhouse, a very small proportion being calcined or otherwise improved.

Cass County, 47 analyses.

	Per cent.
Medium	29.8
Good	23.4
Very good	23.4
Extra	23.4

[1] Phillips, W. B., Iron and steel making in Texas, II: Iron Age, Jan. 11, 1912, pp. 141–143.

Average composition.

	Medium.	Good.	Very good.	Extra.	Average, all analyses.
Metallic iron [Fe]	42.43	48.23	52.33	57.58	48.64
Silica [SiO_2]	18.26	11.85	5.19	3.94	10.64
Alumina [Al_2O_3]	11.33	7.85	5.21	5.21	7.65
Phosphorus [P]	.108	.147	.107	.052	.103
Sulphur [S]	.096	.133	.124	.065	.104

One sample, not included in this classification, contained iron, 60.44; silica, 3.50; phosphorus, 0.038; sulphur, 0.220.

Marion County, 65 analyses.

	Per cent.
Medium	4.6
Good	15.4
Very good	9.3
Extra	70.7

Average composition.

	Medium.	Good.	Very good.	Extra.	Average, all analyses.
Metallic iron [Fe]	43.18	46.69	53.80	57.43	54.91
Silica [SiO_2]	19.55	13.10	4.90	3.27	5.18
Alumina [Al_2O_3]	7.41	8.40	8.33	2.69	4.30
Phosphorus [P]	Trace.	.093	.070	.084	.073
Sulphur [S]	.030	.380	.156	.100	.067

In two of the good ores the silica was 26.43 per cent. In one the alumina was 19.96 per cent and maximum sulphur was 0.735. In one sample of the very good ore the alumina was 16.50 per cent; the maximum sulphur was 0.304. The maximum phosphorus in one sample of the extra ore was 0.22 and the maximum sulphur was 0.22. This county has not only the highest average of extra ore, but the highest general average in metallic iron—viz. 54.91 per cent.

Morris County, 10 analyses.

	Per cent.
Very good	50
Extra	50

Average composition.

	Very good.	Extra.	Average, all analyses.
Metallic iron [Fe]	52.82	56.85	54.83
Silica [SiO_2]	7.76	5.55	6.85
Alumina [Al_2O_3]	4.99	3.39	4.19
Phosphorus [P]	.132	.113	.125
Sulphur [S]	.007	.011	.009

In the very good ores the maximum silica was 13.10, maximum alumina 6.84, and the maximum phosphorus 0.209. Considering that no analyses with less than 51 per cent of iron are quoted from this county, it would appear that the best average of ore is from Morris County, although Marion County has the highest percentage of ore with more than 55 per cent of iron.

Cherokee County, 10 analyses.

	Per cent.
Medium	40
Good	60

Average composition.

	Medium.	Good.	Average, all analyses.
Metallic iron [Fe]	42.34	46.18	44.64
Silica [SiO_2]	22.62	17.19	19.01
Alumina [Al_2O_3]	11.47	10.35	10.94
Phosphorus [P]	.156	.140	.146
Sulphur [S]	.227	.029	.117

In the medium ores the maximum silica was 25.13, the maximum alumina 23.41, the maximum phosphorus 0.315, and the maximum sulphur 0.607. In the good ores alumina was determined in only one sample. The maximum silica was 20.36 and the maximum phosphorus 0.284. * * *

Of the ores represented by these analyses about one-fourth are of medium grade, about one-fourth are good, nearly one-fifth are very good, and nearly one-third are of extra quality and carry from 55 to 60 per cent of iron. It has been already stated that the total area involved in these 14 counties is 10,640 square miles. This must not be taken to mean that all of this territory is ore bearing. This is certainly not the case. Just how much of this area will be productive of workable ores of the medium good, very good, and extra grades is not now known. This is really the vital question, and not what will be the average composition of the ores. There is a vast difference, in so far as concerns shipments of these ores or even their use locally, between material carrying between 40 and 45 per cent of iron and material carrying between 50 and 55 per cent. This difference is acutely accentuated when we consider the ores of extra quality, carrying from 55 to 60 per cent of iron. If the statement that nearly one-third of these ores are of extra quality be true (and we believe it to be so, within a reasonable degree of accuracy), we have in them the very best brown ores in the country. When one considers the easy reducibility of these ores and the cheapness with which they can be mined and handled it may not be extravagant to say that they rank with the best ores of any kind, brown, hematite, or magnetite. What they lack in metallic iron would be more than counterbalanced by reduced cost in smelting.

It may, however, be urged that the extent of the deposits, of whatsoever grade, has not yet been definitely established. This same remark holds good for many other brown-ore deposits, some of which have yielded a very large amount of ore. But while this is true it does not affect the situation in Texas. That brown-ore deposits elsewhere, which have not been thoroughly prospected in advance of the shovel, have yielded and are still yielding large tonnages is

no proof that these deposits will also yield large tonnages. In respect of brown ore it is particularly true that "the proof of the pudding is in the eating." Professor Pick-and-Shovel is the only competent instructor in this school.

DEVELOPMENT OF THE ORE DEPOSITS.

EARLY OPERATIONS.

The deposits of iron ore noted in the preceding pages, as well as many others in northeastern Texas, were known and worked from time to time on a relatively very small scale to supply ore for several small forges and furnaces before and during the Civil War. As a result of the rapid industrial development that followed the war these small furnaces soon became inadequate to compete with larger plants farther east, and they fell into disuse. The ore needed to supply them was obtained from the most favorably exposed ledges, and no thorough prospecting has been undertaken until recent years. Indeed, even the ore needed to supply the moderate-sized blast furnace at Jefferson was obtained only from shallow surface pits, very little mechanical equipment being used either for mining or concentrating the ore. A brief outline of present methods for the development of the deposits is of interest in this connection, for unless they can be worked on a much larger scale than heretofore they are not likely to prove commercially valuable.

PROSPECTING FOR ORE.

Systematic prospecting of a large tract of land bearing iron ore of the residual and nodular type, such as occurs in Cass and the adjoining counties, is by no means a simple and inexpensive operation. A preliminary study of the tract is first made, including examination of all the outcrops and natural sections of the iron-bearing sediments and tests by means of shallow pits and trenches in order to determine if possible whether the expense of further investigation is warranted. If the indications are favorable deeper prospecting may be done by means of test pits, open trenches, and drill holes.

The information to be derived from the prospecting, supplemented by concentration tests and chemical analyses, consists principally in determining the thickness of the cover, the total thickness of the ore-bearing ground, the section which will show approximately the volume ratio of ore to barren material, the weight ratio of ore to barren material, and the character of the ore itself.

The test pits are circular in cross section, about 3 feet in diameter, and as much as 35 feet in depth. They require two men—one for digging, the other for hoisting the excavated material to the surface

by means of a windlass. Lump ore from a pit is usually piled at one side, and the sand and mixed fine ore and dirt are dumped on the other side. All the material from the pit is carefully preserved and forms a basis for the estimation of ratio of ore to dirt. The test pits are generally placed systematically a certain number of yards apart along lines which gridiron the tract except, of course, where surface features such as ravines, trees, or bowlders may interfere. Records of the sections exposed by the pits are carefully kept. A valuable supplement to the test pit is the drill hole. Holes are now being drilled in Cass County ore fields by means of a Keystone drilling outfit. The drill is operated and moved from place to place by means of a traction engine. In the soft or partly consolidated sediments in which the ores are found the machine drills about 90 feet a day, so that two or three holes can be sunk in a day if not too far apart. Such drilling is much more rapid and is less expensive than the sinking of test pits by hand. The drillings are saved on a screen, and the ratio of ore to dirt is determined later. The drill hole does not, of course, yield a visible section, and in that respect is of less value than the pit or trench. By drilling holes close to a few test pits whose sections are on record, the relative value of the information afforded by the two types of openings soon becomes apparent, and the engineer in charge of prospecting learns to what extent he may depend on each type. The application of drilling to prospecting of this sort is a comparatively new feature, and its possibilities have probably not yet been fully realized. Drilling would seem to be a good method of preliminary prospecting, and drilling in connection with sinking of test pits greatly reduces the number of necessary pits and materially lessens the expense.

Prospecting by means of trenches, particularly if the trenches are large and deep, is very expensive, for the work is practically all done by hand. If a trench is driven into a hill there is an advantage in that the excavated material may be wheeled out on a level floor, or perhaps down grade, instead of having to be hoisted out. A prospect trench affords a much better idea of the character of the ore-bearing ground and of the relations of the ore deposits to the inclosing sediments and is probably not exceeded in this respect even by the face of an open-cut mine, for the face of the trench is cut down vertical and clean. For the sake of economy, especially where the ore deposit is largely a residual deposit just below the surface, and where downward concentration of the limonite has resulted in the deposition of layers and masses of ore at a fairly even distance below and approximately parallel with the surface, a trench may be dug in steps and thus the extreme depth at the inner end, most of which might have to be dug in barren ground, may be avoided. If properties which

contain important deposits of ore, of proved value, are to be displayed for sale or for financing, nothing is better than plenty of prospect trenches. Illustrations of certain trenches showing rich ore have been published by Linton.[1]

In connection with the prospecting work outlined above there should be carried on a thorough system of recording the results, preferably one which shall show them in as graphic a way as possible. This is effected by running careful levels over the property, making a large-scale topographic map with 5-foot contour intervals, and plotting each test pit or drill hole accurately on this map. Cross-section sheets are also made, on which all the test openings are shown to scale in their relative altitudes, together with the materials passed through, distinguished by means of appropriate patterns. Later, when concentration tests and ore analyses have been made, these data can be added to the cross-section sheets, which, together with the topographic map, will then contain all the essential data concerning each tested point on the property and enable a reasonably close estimate to be made as to the reserves and grade of available ore.

Such systematic prospecting and recording of results is, of course, very expensive and can not be undertaken unless the preliminary prospecting and natural indications are highly favorable, nor unless the property is large enough to warrant the expense, or several small properties may be prospected together. The engineering and mechanical corps necessary for such work must have a certain amount of special training and knowledge of the field, in order to produce the best results.

In prospecting laminated, bedded ore, such as occurs in Cherokee County, the problem is simpler than in prospecting the concretionary ores of the counties farther north. It is necessary to know the thickness of the cover above the ore, the thickness of the ore bed, its quality, and the altitude at which it lies. As the bed outcrops at a nearly uniform level around the plateau lands, generally on steep slopes, it is most conveniently prospected by pick and shovel on the outcrop. Drills might be used on the level upland, but in places where the cover exceeds 10 feet mining could hardly be carried on under present conditions; therefore systematic prospecting of such areas would be of little use.

RESULTS OF EXPLORATION.

The view taken by Phillips with regard to exploration of the ore fields up to the close of 1911 is shown in the following quotation,[2]

[1] Linton, Robert, Texas iron-ore deposits: Eng. and Min. Jour., Dec. 20, 1913, pp. 1153–1154.

[2] Phillips, W. B., Iron and steel making in Texas, II: Iron Age, Jan. 11, 1912, pp. 142–143.

and it may be added that prospecting during the last three years has been even more encouraging, indicating large reserves of iron ore. Trustworthy estimates of tonnage for the area can not be made, however, unless they are based on definite prospect data for every deposit, and unless every individual ore property is carefully prospected it had best not be included in any estimate.

The work that has been prosecuted during the last two years and which is still in progress has shown, among other important things, that the extent of the very good and extra ores is much larger than anyone had reason to anticipate. Ground which did not appear to be ore bearing at all in a commercial sense has been found to carry very considerable deposits of ore with more than 50 per cent of iron, and under such conditions that it can be mined and loaded for less than $1 a ton. The greater part of these ores are not held in tenacious clay. This is a point much in their favor, as it will diminish in a marked degree the cost of preparing them for shipment. The record of about 2,600 tons, not mined with any special care, neither washed nor screened, shows a content of metallic iron above 57 per cent, with phosphorus ranging from 0.10 to 0.20 per cent.

The clays with which these ores are so closely associated are sandy, friable, of loose texture, and easily removed over a screen or in an ordinary log washer. This means a minimum amount of water and a maximum amount of ore per cubic yard of raw dirt. The three general classes—viz, laminated, concretionary, and conglomerate ore—may be accepted in a broad way, although these three classes may be present in the same locality. So far as the analyses now available are concerned, the concretionary ores are of decidedly better quality than the laminated ores, and these in turn are better than the conglomerate ores. But few of the conglomerate ores now appear to be worth working.

The overburden in the best districts is light and it is probable that a steam shovel would operate to less advantage than plows, scrapers, and pick and shovel. We are inclined to think that a steam shovel will not prove to be the most economical method of handling the greater part of the material in many of the ore districts. It will doubtless find its use here and there, but by no means to the extent now to be seen in Alabama, Georgia, Tennessee, and Virginia.

MINING ORE.

Mining operations in the northern counties have been confined for the most part to the richest outcrops of concretionary ore, and simple hand methods of mining have prevailed. The largest-scale stripping has been done with wheel scrapers. Water is too scarce to render hydraulicking possible. Cheap methods of handling the stripping and the ore are needed, and now, as a result of extensive prospecting in Cass County, there seems to be a fair possibility that steam shovels may be used to advantage over large tracts. This method of mining must, however, be supplemented by concentration of the ore-bearing material, and it is upon the success of this part of the work that the possibility of large-scale mining operations in Cass and the adjoining counties seems most to depend.

Mining of the bedded ore near Rusk, Cherokee County, at present not being worked, was carried on as follows: The cover, which is mainly loose sand, was removed by means of wheel scrapers and dumped into ravines or piled in banks on ground from which the ore had been mined. Areas of several acres were thus stripped at one time. The thickness of the cover stripped rarely exceeded 7 or 8 feet, but a maximum of 10 feet was noted. After the loose cover was stripped off, the "sand cap," or scale of ferruginous hard sandstone, half an inch to 4 inches thick, was split loose from the top of the ore and piled up where it would not interfere with the workings. Then the ore was blasted loose from the bed and the lumps were pried up and broken to smaller sizes with sledges and picks and piled ready for shipment. The ore was loaded into carts by means of forks, and consequently much good ore in fine sizes was left on the ground. The ore of "curly" structure lying in the bed below the laminated top portion tends to crumble on weathering and is commonly referred to as the "buff, crumbly" ore. Probably much ore was thus lost by being allowed to weather too long before it was carried to the furnace. The use of forks appears at first thought to be a wasteful method, but when it is considered that this ore contains a high percentage of alumina, the importance of getting it up free of any underlying clay, even at the sacrifice of some fine ore, is readily apparent. The State mines were operated by convict labor and when in operation were connected with the blast furnace by railroads and tramroads. The method of mining at the other mines near Rusk was similar to that at the State mines, but on a much smaller scale.

CONCENTRATION OF ORE.

The profitable exploitation of the nodular, concretionary, and residual ores in Cass and adjoining counties probably depends more on the successful concentration of these ores than on any other factors connected with their development. Heretofore handpicking of the lump ore from the surface has been about the only method of maintaining a high-grade product, but this method is wasteful and altogether too slow and expensive to be continued. What is needed is a method or a combination of methods of ore concentration that will make it possible to work on a large scale the maximum thickness of ore-bearing ground, and deliver ore concentrates of high grade at a cost commensurate with the value of the ore recovered.

Experiments are under way in Cass County which involve washing the mine-run ore in revolving screens, picking the oversizes on a picking belt, and crushing and jigging the residue when separated from the loose sand and clay. In commercial operations the ore will first be run through log washers. The final step consists in calcining the

ore to drive off the combined water from the limonite and the carbon dioxide from the carbonate ore. The washing and jigging experiments which have been carried on in a small but well-equipped plant have been designed mainly to ascertain the ratio of ore to dirt removed from the test holes, and although they were not made on a commercial scale they seem to demonstrate that the ore can be fairly well cleaned by this method, the percentage of silica being materially reduced and the percentage of iron proportionately increased.

Surface water is none too abundant in this region at certain seasons of the year, and the maintenance of steady and adequate supplies of water for large-scale operations may prove one of the most serious problems to be solved. There are many small creeks in the region which might be utilized to supply reservoirs, and the water after having been used once can be conserved for further use by means of settling basins. Deep wells are also expected to play a part in furnishing water for ore washing.

For calcining ore northeastern Texas is well supplied with fuel. There is an abundance of wood at present, lignite occurs in many places, and the Caddo oil and gas field is near by and already supplies natural gas to several towns in Cass County.

In 1914 an investigation was undertaken by William B. Phillips to ascertain whether the Goltra beneficiation process is applicable to the brown iron ores of northeastern Texas. By the Goltra process the use of water is dispensed with, the ore is cleaned by means of a current of hot air and properly located screens, and the fines are separated magnetically. Phillips[1] describes the process as follows:

The material from the bank of ore, containing ore, sand, clay, earth, chert, sandrock, etc., is fed into a steel cylinder partly lined with fire brick. This cylinder is 125 feet long and 10 feet in diameter. It is inclined three-quarters of an inch to the foot and makes one complete revolution per minute. The travel of the material down and through this cylinder is at the rate of about 2 feet per minute, so that it reaches the lower end in from 45 to 60 minutes after feeding.

At the lower end of the cylinder a blast of ignited pulverized coal is blown in by an Aero pulverizer, the fineness of the coal being from 80 to 100 mesh. At the upper end of the cylinder a large fan is installed, with a capacity of 35,000 cubic feet of air per minute, and this draws the heated air through the cylinder and discharges it, with the fine dust, into a dust catcher. During the drying of the material the temperature of the lower part of the cylinder is kept at about 300° F., the temperature at the upper end being about 200° F., or even less.

The material is thus dried very slowly and completely, and during the drying the fine clay, sand, earth, etc., are swept out of the cylinder by the current of heated air. From this first cylinder the thoroughly dry material is sent to a gyratory crusher, set for 2 to 2½ inches. From the crusher the material goes to a revolving three-size screen, the inner openings, punched round, being three-

[1] Phillips, W. B., Concentration by the Goltra process: Iron Age, Nov. 12, 1914, pp. 1148–1150.

fourths inch, and the second screen, with round openings, being one-half inch. The outer screen has $\frac{1}{16}$-inch slotted openings.

The material over $\frac{3}{4}$-inch screen is hand picked on a picker belt and goes with all of the stuff, except such as passes the $\frac{1}{16}$-inch outer screen, into storage bins. The material through the $\frac{1}{16}$-inch outer screen goes into a reject bin.

The material from the revolving screen, all sizes above one-sixteenth inch, is conveyed to a storage bin which discharges into a second cylinder 125 feet long and 9 feet in diameter, partly lined with fire brick. This cylinder has the same slope as the first cylinder and the same revolutions per minute. It is heated in the same manner as the first cylinder, but the temperature is much higher, so that the material reaches the lower end at a bright-red heat—about 1,000° F. The heated air is drawn through this cylinder in the same manner as through the first cylinder, and the fine dust, etc., is discharged into a dust chamber.

From the lower end of this second cylinder, which may be termed the calciner, as distinguished from the dryer, the red-hot ore is screened over a revolving screen with $\frac{1}{4}$-inch punched round holes. The "overs" from this screen are cooled and hand picked over a picker belt and go direct to the loading bins above the railroad tracks. The red-hot material through the $\frac{1}{4}$-inch screen just mentioned goes to what is known as the reducer. This is a closely sealed steel cylinder, in which the ore is sprayed with crude petroleum and rendered highly magnetic. From this reducer the magnetized fine ore goes to screens where it is classified to one-fourth and one-sixteenth inch, these separate sizes being sent to Ball-Norton magnetic separators.

This, in brief, is the Goltra process. It is an air-washing process, instead of a water-washing process, and employs magnetization and magnetic separation of the fine material, instead of jigging it.

A Goltra plant has been built at Waukon, Iowa, in an attempt to render marketable the brown ore occurring near that place. In order to test the Texas ores Phillips shipped 14 carloads of Texas brown ore, aggregating about 338 tons in weight, to Waukon and put it through this concentrating process. The following analyses show the average composition of the ore at various stages:

Average composition of Texas brown ore concentrated at Waukon, Iowa, by Goltra process.

	1	2	3
Metallic iron [Fe]	32.74	42.36	55.23
Silica [SiO_2]	26.77	26.80	14.80
Alumina [Al_2O_3]	6.65	9.89	10.43
Sulphur [S]	.041	.003	Trace.
Phosphorus [P]	.075	.085	.098
Free water	11.33	....	....
Combined water	8.70	....	....

1. Average of samples of raw ore from each of 14 cars when unloaded at Waukon.
2. Average composition of ore after drying.
3. Composition of ore after calcining (excluding magnetic concentrates).

Of these analyses Phillips says:

The meaning of these figures is that a comparatively worthless material, the raw ore, is changed into an excellent product, well adapted for blast-furnace use.

The mere statement of the composition of the calcined ore does not convey the full sense of its merits. Its physical qualities, especially the porosity so essential for easy reduction in the furnace, are of equal if not greater importance. It would seem to be practically impossible to take a raw brown ore of similar character and make from it a better product than this calcined ore. In quantity it comprises 22.22 per cent of the dried ore and 38.76 per cent of the material from the calciner, which is to be classed as ore.

Embodying the results of the detailed analyses [both physical and chemical] of each separation in one general statement, we have:

Dry ore to be accounted for, 267.32 tons.

Ore recovered.

	Per cent of dry ore.	Per cent of material to be classed as ore.	Per cent of iron.
(a) Size, ½ inch and over, not magnetic	22.22	38.76	55.23
(b) Magnetic heads, partly oversize	4.39	7.55	55.23
(c) Magnetic heads, ¼–½ inch	.52	.90	63.33
(d) Magnetic tails	4.04	7.00	34.05
(e) Unfinished material, ½ inch and under	26.87	35.87	52.36
(f) Clean-up at separator	3.42	5.89	50.00
(g) Leakage at reducer feed	2.73	4.03	51.58
		100.00	

What has been done, therefore, is to take a raw ore containing 32.74 per cent of iron and bring 46 per cent of it up to 52 per cent of iron. Taking the free and combined water as material which has to be removed and which represents no possibilities of concentration, being a detriment to the ore, we have taken a material which in the ground carries 32.74 per cent of iron and have brought the iron up to 52 per cent. At the same time the physical nature of the ore has been greatly improved. The loss in weight during the operation, extending from the ore "bank" to the loading bins at the plant, is 54 per cent, of which 20 per cent is free and combined water. This leaves 34 per cent, or 115.13 tons of material, a portion of which may be suitable for further concentration.

Looking at this matter from the standpoint of clean ore, it is very satisfactory. The free and combined water are completely removed, the clay is almost completely removed, and the physical condition of the finished ore leaves nothing to be desired.

The greatest success is reached in preparing calcined ore over one-half inch in size. This product carries over 55 per cent of iron, and its physical condition is ideal.

Where the process is weak at present is in the treatment of the calcined ore through a ½-inch screen, this material being sent to the "reducer" for magnetization and then to magnetic separators.

While some of the magnetic heads carry 63 per cent of iron, yet the intermediate products and the tails carry too little iron as chargeable against the cost of concentration.

The finished product obtained by this process is excellently adapted for use in the blast furnace. The free and combined water are completely, and the clay, sand, etc., almost completely, removed. The sulphur, except in the case of some magnetic concentrates, is eliminated. The physical nature of the ore is greatly improved, particularly in respect to its porosity and easy reducibility in the blast furnace.

The loss in free and combined water in the ore tested was 20 per cent. From the ore received at Waukon we removed 67.83 tons of water, or 16,279 gallons. Good brown ore of 47 per cent iron as sent to the furnaces in Alabama will carry 14 per cent of water (free and combined) per ton of ore, and this water goes into the furnace and must be evaporated by the heat within the furnace, which otherwise would be used in smelting the stock.

UTILIZATION OF THE ORE.

GENERAL CONDITIONS.

The brown ores of northeastern Texas have been utilized to a minor extent for the manufacture of iron in small local forges or furnaces in almost every county in which a good-sized deposit of ore occurs. Some of these furnaces have already been mentioned. This form of industrial activity existed mainly between 1856 and 1870. Between 1870 and 1909 iron was manufactured from time to time in five or more small charcoal blast furnaces, notes on which are given below. Since the last of these furnaces went out of blast several plans have been made to establish iron and steel works on the Gulf coast, as well as at points between the ore field and the Oklahoma coking-coal field. A movement is now under way to establish an iron and steel industry at Texas City, Tex. The recent conditions of the iron and steel markets and the general financial situation have not, however, been favorable for the furtherance of such enterprises, and in the meantime some attention has been given to the shipment of iron ore to blast furnaces in Alabama and on the Atlantic seaboard.

Phillips,[1] who has given much thought to the utilization of the Texas brown ore, has stated his belief that the ore should be utilized in the northeastern part of the State rather than an attempt be made to build iron and steel works on the Gulf coast. With reference to the practical iron and steel plant he says:

Iron and steel works of the size to make profitable use of by-product ovens are not now needed in Texas or the Southwest. Instead, it seems to us that a blast-furnace plant producing 250 to 300 tons of pig iron a day, with a steel plant whose product would enter into the lighter finished forms, is much more to the point. The initial investment would be much less and the character of the product could be kept in closer touch with actual demands. The logical location for such a plant would be in east or northeast Texas, in close proximity to the ore fields and within reach of the coking coal of Oklahoma and Arkansas. So far as known there is no good coking coal in Texas and the nearer an iron furnace is to regular supplies of coke the better. Coking coal or coke will have to be brought from some other State. * * * The most favorable outlook in Texas and the Southwest for the manufacture of iron and steel is in the direction of a blast furnace with auxiliary steel plant, not operated so much with reference to the demand for the heavier forms, such as structural shapes, plates, or rails, as to the demand for cotton ties, wire

[1] Phillips, W. B., Iron and steel making in Texas: Iron Age, Jan. 4, 1912, pp. 14–16.

fencing, wire nails, perforated metal, pipe, and light steel castings. That such an enterprise would succeed here, under proper management is, we think, well within the bounds of probability.

TEXAS BLAST FURNACES.[1]

One of the early blast furnaces to utilize the local ores was the Loo Ellen furnace at Kelleyville, Marion County, 5 miles north of Jefferson, which was put into blast in 1870. The stack was originally square, but was rebuilt in round form in 1874. The height, originally 34 feet, became 45 feet; the bosh diameter was 9 feet, and the capacity of the furnace was 10 tons of metal a day. The product was at first hot-blast charcoal soft foundry iron, and later a hard iron especially suitable for chilled castings, such as car wheels, was made. Limestone for flux was obtained near Dallas.

A larger and more modern charcoal blast furnace was put into blast March 15, 1891, on the north edge of the town of Jefferson, and for several years this furnace was supplied with ore from deposits in Cass, Marion, and Morris counties adjacent to the railroads. Its annual capacity was rated at 13,500 tons. The plant has been inactive for 10 or 12 years.

There are three small blast furnaces in the vicinity of Rusk, Cherokee County, that were built to utilize the brown ore of the plateau, but all are now idle. The oldest furnace and the one which has had the most useful history is the property of the State of Texas. It was originally called the Old Alcalde, and was first put into blast in February, 1884, with a stack 55 feet high and a bosh diameter of 9½ feet. It was designed for an output of 25 tons a day, or 7,000 tons a year. It stands about three-quarters of a mile northeast of the center of Rusk, just outside of the walls of the State penitentiary, and has trackage connections with the Texas & New Orleans Railroad and the Texas State Railroad. The blast furnace and the associated ore mines were operated by convict labor, and considerable of the pig iron produced was remelted and cast into iron pipe at an adjoining pipe foundry, also owned and operated by the State. The furnace was originally built to use charcoal, but later it was rebuilt and ran on coke. The furnace has been out of blast since December, 1909, but in 1913 it was relined and put in good shape by the Texas Iron Association, which had leased the furnace and planned to revive operations. Owing to unfavorable business conditions and other reasons the lease was permitted to lapse.[2]

[1] Dumble, E. T., Reports on the iron-ore district of east Texas: Texas Geol. Survey, Second Ann. Rept. (for 1890), p. 15, 1891.
Walker, J. B., idem, pp. 293–294.
Phillips, W. B., The iron resources of Texas: Western Pennsylvania Proc., vol. 18, No. 2, p. 77, 1902.

[2] See Min. and Eng. World, June 27, 1914, p. 1210.

The Tassie Belle furnace, 2 miles southeast of Rusk, was put into blast in November, 1890. This furnace stands on the east side of the St. Louis Southwestern Railway and during its few years of activity was surrounded by a flourishing town known as New Birmingham. It was operated as a charcoal furnace and two of the old charcoal kilns still stand. The capacity was rated at 13,500 tons a year. The furnace is now in a very dilapidated condition, the top house and elevator ways have fallen down, the machinery has been allowed to rust and to be dismantled, and the ground is covered by second-growth pine.

The last furnace to be built in Cherokee County was the Star and Crescent, which was put into blast in November, 1891. It stands on the south side of the St. Louis Southwestern Railway about three-quarters of a mile east of Rusk. This furnace is said to have been operated as late as 1907. The equipment is in better shape than that of the Tassie Belle, and 31 brick charcoal kilns remain standing. The capacity was rated at 18,000 tons of pig iron a year.

SHIPMENTS OF ORE TO OTHER STATES.

About 1907–8 approximately 2,200 tons of brown ore (mostly from Marion and Cass counties) was shipped to the Birmingham district, Ala., a distance by rail of about 500 miles. The ore was mostly in selected lumps, and its average content of metallic iron was above 57 per cent, with phosphorus ranging from 0.10 to 0.20 per cent. It was reported to be well adapted for the production of basic open-hearth steel. The freight rate was $2.20 a ton.[1]

In 1910 a sample lot of 568 tons of brown ore was shipped to Philadelphia by way of Texas City, on Galveston Bay. The rail haul was about 300 miles. The ore was similar in quality to that sent to Birmingham. A rate of $2.30 a ton to Philadelphia is reported to have been quoted to one of the companies.[2]

Two steamer cargoes of high-grade brown ore were shipped from northwestern Marion County to Philadelphia, by way of the Port Bolivar Iron Ore Railway and the Atchison, Topeka & Santa Fe Railway to the Gulf, in the summer of 1913. The analyses of this ore are given on page 88. It is reported by the shippers that the ore gave excellent satisfaction in the Alan Wood Iron & Steel Co.'s furnaces, where it was used.

Concerning the supply of the highest grade of ore Phillips[3] says:

While it may not be possible to secure large and regular shipments of 57 per cent ore from east Texas, yet we believe there are very large supplies of 50 per

[1] Phillips, W. B., Iron and steel making in Texas, I: Iron Age, Jan. 4, 1912, p. 14.

[2] Linton, Robert, Texas iron-ore deposits: Eng. and Min. Jour., Dec. 20, 1913, pp. 1154–1156.

[3] Phillips, W. B., op. cit., p. 15.

cent ore which can be mined and loaded for 85 cents to $1 per ton. Such ore could be laid down in the stockyard of a furnace at Jefferson for $1.25 a ton and at Texarkana for $1.50 a ton. The ore cost of a ton of pig iron should not exceed $3 at either of these localities.

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QUICKSILVER DEPOSITS OF THE MAZATZAL RANGE, ARIZONA.

By F. L. Ransome.

FIELD WORK.

The examination on which the following notes are based was made in October and November, 1914, and occupied in all about 10 days. Particular acknowledgment is due to Mr. E. H. Bowman and Mr. William Reynolds, of Phoenix, for information and personal guidance and for considerate hospitality of a quality rare even among those friends of the geologist, the western prospectors. A part of the examination was made in company with Mr. W. Spencer Hutchinson, mining engineer, of Boston, who came a few days after my arrival, to investigate for his clients the possibility of mining these deposits. To him and to his associate, Mr. J. V. N. Dorr, of New York, I am indebted for a manuscript copy of their report, with permission to make such use of the data it contains, particularly of the assays, as should be deemed appropriate.

SITUATION AND MODES OF ACCESS.

The Mazatzal Range is a prominent well-defined mountain ridge in central Arizona (see fig. 6), with a trend a little west of north and a length of about 40 miles. It lies between Verde River on the west and Tonto Creek on the east, both streams flowing southward into Salt River. At the north end of the range is North Peak, which has an altitude of about 7,600 feet. Near the south end, the mountain known as Four Peaks, a noted landmark throughout a large area in central Arizona, attains an elevation of 7,645 feet. From North Peak to Salt River the crest of the range has been made the boundary line between Gila County on the east and Maricopa County on the west.

The Mazatzal Range is one of many mountain ridges of approximately rectilinear plan, all nearly parallel in trend, that characterize the belt of rugged country bordering the Arizona Plateau along its southwest side. North Peak is 15 miles south of and in full view of the great Mogollon escarpment, which in this part of Arizona marks imposingly the edge of that plateau. The entire range is in the Tonto National Forest.

The quicksilver deposits about to be described occur in a strip of country about 6 miles long that extends northeastward across the Mazatzal Range in the vicinity of Pine Butte, 11 miles south of North Peak. Mount Ord, one of the prominent and well-known peaks of the range, is a little less than 6 miles south of the quicksilver belt.

All the claims are in the Sunflower mining district and most of them lie in the northwest corner of the Roosevelt quadrangle, of which a topographic map on the scale of 1:125,000 (approximately 2

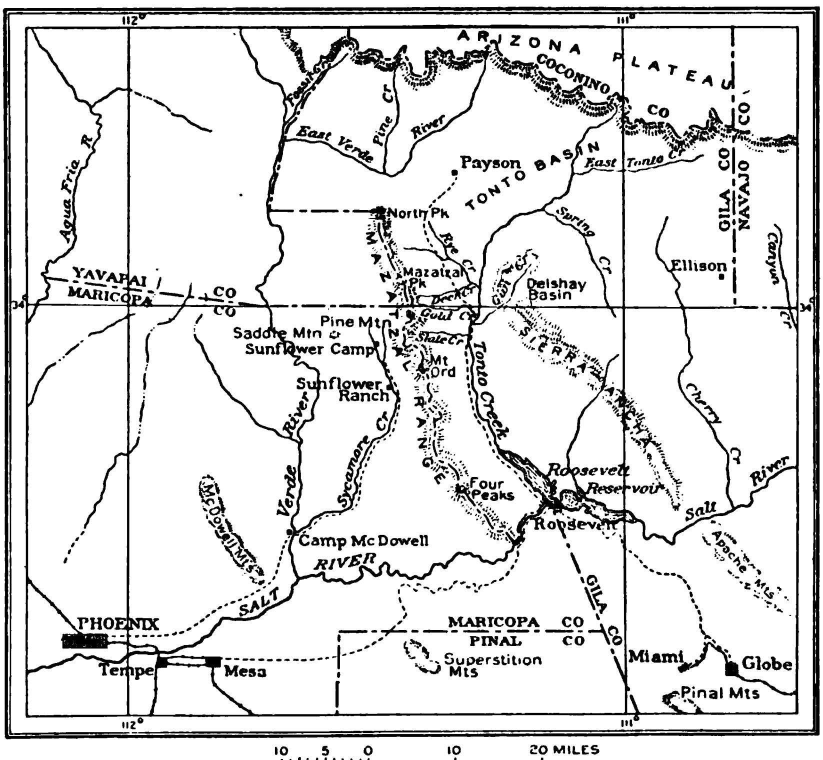


FIGURE 6.—Outline sketch map of the Mazatzal Range and surrounding region in central Arizona.

miles to the inch) has been issued by the Geological Survey. Some of them, however, extend into the Verde quadrangle, of which the best map obtainable is a very unsatisfactory reconnaissance sheet published in 1885 on the scale of 1:250,000 (nearly 4 miles to the inch).

Sunflower camp, near which most of the development work on the west slope of the range has been done, is at an elevation of about 4,350 feet, on the west fork of Sycamore Creek, a tributary of the Verde which enters that stream opposite old Fort McDowell. The camp is about 70 miles from Phoenix by road and trail. The road

traverses the flat desert country north of Salt River and crosses the southern end of the McDowell Mountains to Fort McDowell. Here the Verde is forded and the road continues up the generally dry bed of Sycamore Creek. At the forks of the creek, about 4 miles north of the Sunflower ranch, the road ends and the remaining 3 miles of the journey must be traversed by trail. The road is rough at the best, and at the time of visit, in October, 1914, much of it was impassable for heavy wagons. Freighting from Phoenix or Mesa to the Sunflower camp was reported to cost from \$40 to \$50 a ton.

Bowman's camp, about a mile northwest of Sunflower camp and about 800 feet higher, is reached by a steep rough trail. Martin's camp, on the east fork of Sycamore Creek, is about 2 miles northeast of Sunflower camp, in a straight line. It is most easily reached by trail from the forks of Sycamore Creek. About half a mile northwest of Martin's camp is Bowman & Reynolds's Maricopa camp.

The claims in Gila County, on the east slope of the range, are most readily accessible from Tonto Creek, along which an automobile stage line runs with daily service between Roosevelt and Payson. Connections are made at Roosevelt for Globe and Phoenix. From Hardt's ranch, about 5 miles south of Deer Creek, a trail goes west over a local divide to Gold Creek and up that creek to Reynold's camp, near its head. The distance from Phoenix to Roosevelt is about 75 miles; from Roosevelt to Hardt's ranch 37 miles, and from the ranch to Reynolds's camp 5 miles.

Most of these prospects on the east side of the range are on slopes that drain into Gold Creek, a stream that flows eastward and joins Tonto Creek about half a mile above the mouth of Gun Creek. Some claims, however, nearly due east of Pine Butte, are on the side of a ridge that drains to Cane Creek, a tributary of Slate Creek which in turn flows into the Tonto about 2½ miles south of Gun Creek.

The quicksilver belt is all in rough, mountainous country ranging in elevation from 4,000 to 6,000 feet. The slopes are steep and the streams flow in narrow ravines. Water is not plentiful, but enough could probably be obtained from springs and by pumping from the larger stream bottoms to suffice for metallurgical operations on a small scale. Pines and cypresses are fairly abundant on some of the ridges, and oaks, sycamores, and other deciduous trees flourish along the watercourses. Firewood delivered at the furnace of the Sunflower Cinnabar Mining Co. costs \$4 a cord.

HISTORY.

Cinnabar was discovered in the Sunflower district in October, 1911, by E. H. Bowman, of Phoenix, while prospecting for gold. He located the Native, Packover, Titanic, Jasper, Go By, and Ione claims.

These were purchased for $10,000 by the Sunflower Cinnabar Mining Co., organized in February, 1913, and capitalized at $1,000,000. The company acquired nine other claims in addition to those purchased from Bowman. In September, 1913, a 10-retort furnace was completed by the company. At the time of visit 2 flasks of quicksilver had been shipped and about 3 flasks were in hand.

Other claims were located soon after Bowman's discovery, but the Gila County deposits were not found until the spring of 1914.

GENERAL GEOLOGY.

The geology of the Mazatzal Range is not yet known in detail. At the south end of the range the Paleozoic era is represented by the same formations (see fig. 7) that occur in the Globe and Ray quadrangles,[1] and a typical section of these rocks from the pre-Cambrian granite to the Carboniferous limestone is well displayed in the canyon of Salt River near the Roosevelt dam. Four Peaks is composed in part of a medium-grained gneissic quartz-mica diorite, presumably pre-Cambrian. Between Four Peaks and Mount Ord the range, as seen from the valleys, appears to consist principally of pre-Cambrian granitic rocks. The prevailing rock along Sycamore Creek on the west side of the range is a rather coarse porphyritic granite similar to granite known to be of pre-Cambrian age in other localities in Arizona.

As may be seen in the steep sides of many flat-topped buttes and ridges, this granite is overlain by coarse granitic detritus, beds of tuff, and a capping of lava, generally basalt. Some dark dikes, presumably basalt, cut through the arkose and tuff. All these rocks are probably of Tertiary age.

On the north slope of Mount Ord the granite is succeeded by a belt of schistose and slaty rocks which crosses the range obliquely with a northeast-southwest trend. As exposed in the Mazatzal Range this belt has a width roughly estimated at 5 miles. To the northeast, where it crosses Tonto Basin and extends past the north end of the Sierra Ancha, the area of schistose rocks is probably at least 15 miles wide.

The descriptions of A. B. Reagan[2] and his rough reconnaissance map are not altogether clear on this point, but the belt of schistose rocks, irregularly overlapped in places by younger formations, appears to extend eastward across the upper parts of Cherry, Canyon, and Cibicu creeks, beyond which it probably passes under the horizontal beds of the Arizona Plateau. Toward the southwest the schists are exposed for only a mile or two beyond Sycamore Creek, passing in that

[1] Ransome, F. L., The Paleozoic section of the Ray quadrangle, Ariz.: Washington Acad. Sci. Jour., vol. 5, pp. 380-388, 1915.

[2] Geology of the Fort Apache region in Arizona: Am. Geologist, vol. 32, pp. 265-308, 1903.

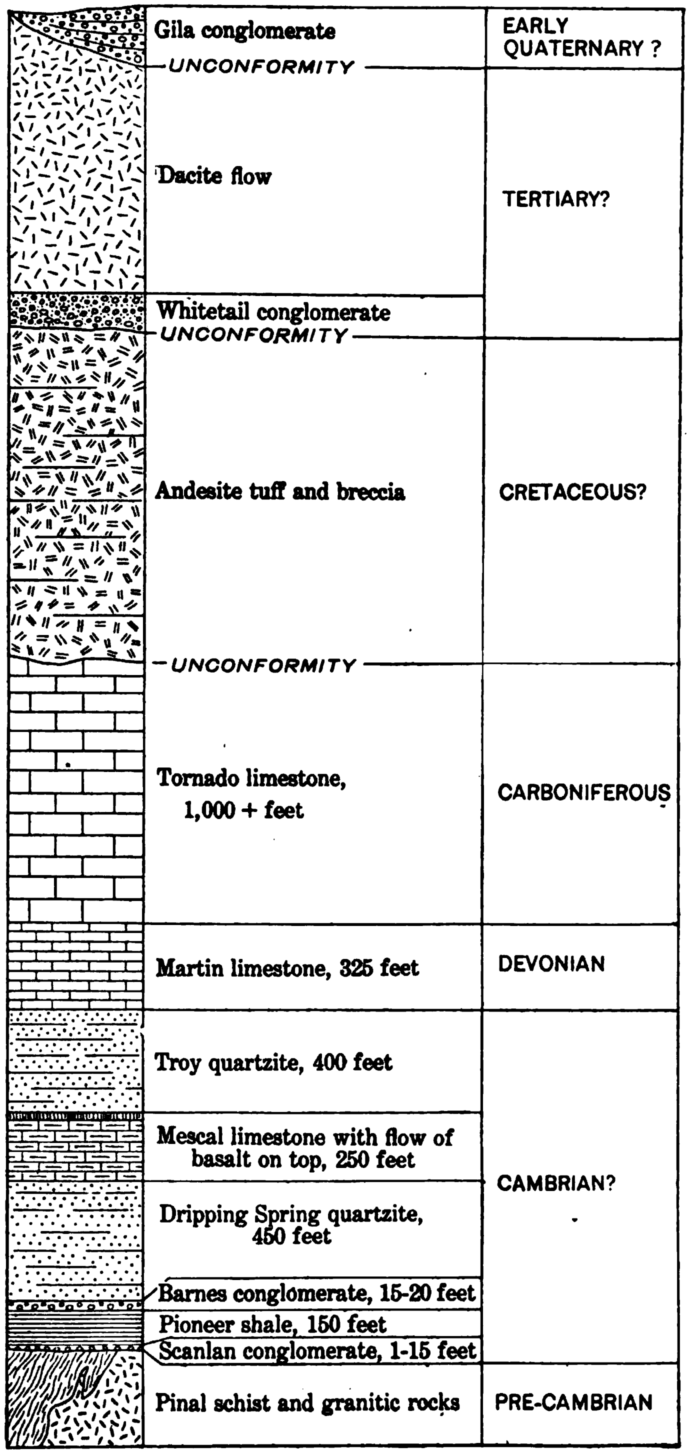


FIGURE 7.—Generalized columnar section of the region adjacent to Ray, Ariz.

direction beneath Tertiary lavas. The southeast boundary of the schist belt crosses Sycamore Creek near where the stream forks, about 4 miles north of the Sunflower ranch. The line swings across the northern slope of Mount Ord, between the granitic summit of that peak and Slate Creek, crosses Tonto Creek near the mouth of Gun Creek and passes through Delshay Basin, near the north end of the Sierra Ancha. The northwest boundary crosses the Mazatzal Range just south of the rugged quartzite masses of Mazatzal Peak, Deer Creek, which heads on the south side of the peak, being chiefly in schist. It passes across Tonto Basin a mile or two south of Payson.

This belt of schist, lying between areas where most of the fundamental rock is pre-Cambrian granite, appears to coincide with a ridge or barrier of considerable importance in Paleozoic time. Southeast of it the Paleozoic section is, in general, that of the Globe-Ray region. Northwest of it the section corresponds in its major features to the Grand Canyon sequence. The existence of such a ridge east of the region here described in what he interprets as Algonkian time has been suggested by Reagan.[1] He does not, however, appear to have recognized the coincidence of this ridge with a line of division between Paleozoic sections of different character. These differences it is hoped to bring out more fully and clearly in another paper. It must suffice to state here that they relate chiefly to what are supposed to be the Cambrian strata, the Tonto group on the north of the schist belt being very different from the Apache group on the south of that belt.

Associated with the schists and slates in the Mazatzal Range and at the north end of the Sierra Ancha are great masses of quartzite, accompanied by some conglomerate and shale. These rocks are clearly older than the Apache and Tonto groups (Cambrian). They make up Mazatzal Peak and apparently most of the northern part of the Mazatzal Range. They are present on the north side of Delshay Basin, much folded and faulted and unconformably overlain by the nearly horizontal Paleozoic beds of the Apache group. At Natural Bridge, also, on Pine Creek, 11 miles north of North Peak, uptilted hard conglomerate and quartzite rest on granite and are unconformably overlain by the horizontal Paleozoic beds. The older rocks in places project as hills through the Cambrian sandstone into the overlying Devonian (?) limestone. This conglomerate and quartzite are probably the same as the pre-Cambrian conglomerate and quartzite of the Mazatzal Range.

Some of the quartzite beds of the Mazatzal Range are infolded with the schists and are possibly an integral part of the schist series. The larger bodies of quartzite, however, such as that of Mazatzal Peak,

[1] Op. cit., p. 277.

are associated with beds of conglomerate that contain flakes of schist showing that the quartzite, while pre-Cambrian, is distinctly younger than the schist. Whether the pre-Cambrian quartzites of this region are all or only in part younger than the schist can be determined only by detailed work.

The volcanic rocks under which the schist passes at its southwest end have a thickness of about 1,000 feet on Saddle Mountain. At the base is a soft brown tuff, andesitic or basaltic, with many schist fragments. This appeared to be from 50 to 60 feet thick. It is overlain by light-gray fine-grained andesitic tuff of approximately the same thickness. Above this lies about 200 feet of coarse andesitic tuff-breccia, the fragments being mostly a light-gray hornblende-biotite andesite. This is succeeded by about 300 feet of andesitic flow breccia, which appears to pass upward without recognizable plane of demarcation into a somewhat porous pink lava which, although resembling the dacite of the Globe-Ray region, proved on microscopic examination to be a fresh hornblende andesite with glassy groundmass. This flow or part of the flow is at least 400 feet thick and forms the top of the mountain.

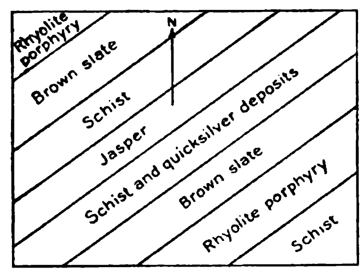


FIGURE 8.—Diagram showing relative positions of rock zones in southwestern part of the Mazatzal quicksilver belt, Ariz.

GEOLOGIC RELATIONS OF THE QUICKSILVER DEPOSITS.

The schistose rocks in which the cinnabar occurs strike generally northeastward, and the planes of schistosity are nearly vertical. The southwestern part of this schist belt is divisible longitudinally into at least eight zones, indicated diagrammatically in figure 8. The southwest zone—the zone first crossed in ascending the west fork of Sycamore Creek—consists of gray sericitic schist, in part fissile and slaty and containing some layers of greenstone schist. This is about 1½ miles wide. It is succeeded by a boldly outcropping dikelike mass of yellow rhyolite porphyry, perhaps one-third of a mile wide. This rock is schistose on the sides of the mass and appears to have been affected by the same forces that gave the schists their present character. Under the microscope the least altered varieties of the porphyry show considerable metamorphism. The quartz phenocrysts have been enlarged by secondary quartz, and the groundmass is a secondary aggregate of quartz and sericite. Northwest of the rhyolite porphyry is a zone of fissile brown slate, probably between one-third and one-half of a mile wide. This is succeeded by a zone of nearly the same width of sericitic schist con-

taining here and there layers of squeezed conglomerate, of slate, of interlaminated hematite and jasper, of limestone, and of greenstone schist. This is the zone in which most of the cinnabar deposits in Maricopa County have been found. Northwest of it is a zone of a very conspicuous rock consisting of thin layers of yellowish dolomitic limestone and bright red jasper. The layers are considerably contorted and the brittle jasper in particular appears to have been broken and displaced by movement in the mass, so that in places the limestone is crowded with red fragments. This rock is hard and resistant and forms prominent outcrops. The zone, however, is irregular in width and apparently is discontinuous. Northwest of the jasper zone is a zone of schist which, although similar to that on the southeast side of the jasper, appears to contain a larger proportion of squeezed grits and conglomerates. The pebbles are in part flaky and suggest derivation from older schists. A second zone of brown slate lies northwest of this schist and this is succeeded by a second zone of rhyolite porphyry.

It will thus be seen that in the southwestern part of the quicksilver belt the distribution of the rocks is such as to suggest that the jasper zone occupies the axis of a compressed syncline or anticline. Toward the northeast, on the east slope of the Mazatzal Range, the symmetrical arrangement of the rock zones is less evident.

The rhyolite porphyry which is so prominent on the west fork of Sycamore Creek, near the Sunflower camp, was not seen on the east fork. At the place where the porphyry might be expected that stream cuts through at least 40 feet of coarse conglomerate, which contains pebbles of slate and red jasper and seems to be part of the schist series. South of the conglomerate, and also seemingly involved in the schist complex, is a considerable body of reddish altered igneous rock, apparently rhyolite. North of the conglomerate is the first zone of brown slate and then the second schist zone. The brown-slate zone continues northeastward through the saddle just north of Pine Butte, on the crest of the Mazatzal Range, and is said to die out on Deer Creek, on the east slope of that range. The top of Pine Butte is rhyolite porphyry.

In Gila County, east of Pine Butte, the quicksilver deposits appear to occur in the southeast schist zone, the one crossed first in ascending Sycamore Creek, and therefore not the same zone as that containing the deposit on the west fork of Sycamore Creek.

Just west of Reynolds's camp, near the head of Gold Creek, is a mass, several hundred feet wide, of very fine grained reddish-brown rock, which was supposed in the field to be a dike in the schist. It is not schistose and may therefore be later than the general metamorphism recorded by the schists. Nevertheless the microscope shows

considerable alteration. The groundmass retains no recognizable igneous texture and is traversed by a network of microscopic veinlets of sericite. The rock is apparently an altered rhyolite, and its felsitic character suggests that it may be extrusive.

Small dikes of diorite porphyry appear to be fairly abundant in schists along Gold Creek and on the ridge separating Gold Creek from Hardt Creek, the next stream to the north.

GENERAL CHARACTER OF THE DEPOSITS.

The quicksilver deposits of the Sunflower district are lodes, which in general conform to the lamination of the schist in which they lie. In the southwestern part of the quicksilver belt three approximately parallel lodes are recognized. These are from 300 to 500 feet apart. The middle or Packover lode appears to be the longest and the best metallized and is the one on which nearly all development work has been done.

The lodes consist of veinlets, films, and specks of cinnabar in schist and as a rule have no definite walls. Associated with the cinnabar, particularly in the larger veinlets, is more or less gangue. The usual gangue-forming minerals below the zone of oxidation are calcite; a buff ferruginous carbonate, probably of variable composition, which leaves a residue of limonite on weathering; and quartz. Some barite is reported by Mr. Bowman. Sulphides other than cinnabar are rare within the veinlets, although small crystals of pyrite closely associated with flecks of cinnabar are fairly abundant in some of the schist near veinlets. A very little chalcopyrite was noted. In some ore taken from the Tatum group by Mr. Reynolds and received since the field examination was made, specularite occurs in small aggregates of glistening scales associated with cinnabar in a quartz and ferruginous carbonate gangue. In ore taken from a cut in the Packover lode on the Packover claim are a few minute specks of a bright-gray metallic mineral, which, as tested by W. T. Schaller, of the Geological Survey, gave off no sublimate in a closed tube and no reaction for copper. It is therefore probably not tetrahedrite. Neither does it appear to be stibnite. The quantity obtained was too small to permit identification of the mineral. Globules of native quicksilver occur with some of the cinnabar.

Most of the veinlets or stringers lie in the cleavage planes of the schist and range from mere films to veins 6 inches thick. Stringers over an inch thick are exceptional. In some places stringers cut across the schistosity. As a rule the veinlets interleaved with the schist are not individually persistent for more than a few feet; they thin out and are succeeded by others. Many of the stringers that cut across the schists are very irregular in course and width. The abun-

dance of the cinnabar veinlets and the total width of the metallized zone vary greatly from place to place. At one surface exposure of the Packover lode on the Go By claim the schist for a width of at least 75 feet contains little veinlets of cinnabar and gangue, all less than 3 inches wide and most of them less than 1 inch wide. This zone of veinlets is not bounded by definite walls, and the schists probably contain some cinnabar outside of the 75-foot belt. At this locality Mr. Hutchinson, by careful prospecting and counting, established the existence of 17 veinlets in a width of 9 feet. The aggregate thickness of these veinlets was estimated by him at 15 inches. Another count 50 feet away on the same lode gave substantially the same result. Besides occurring in the veinlets the cinnabar, particularly near the veinlets, is disseminated as specks and small irregular blotches through the schist.

A sample taken by Mr. Hutchinson at the locality just indicated, by making two cuts across the 9-foot zone and rejecting so far as possible the barren schist between the stringers, yielded on assay 3.60 per cent of quicksilver. That is, the result represents approximately the contents of an aggregate width of 15 inches of stringers out of a total width of 9 feet of lode. It may be estimated roughly from the foregoing data that a continuous sample across the 9 feet might assay from 0.5 to 1 per cent of quicksilver.

Although the individual veinlets are not persistent, the Packover lode as a whole is traceable with reasonable certainty for at least 3 miles. It is not continuously exposed for that distance, but its presence is indicated by the occurrence of cinnabar here and there along its outcrop.

As a rule the cinnabar lodes do not crop out conspicuously. The course of the lode if recognizable at all as a topographic feature is more commonly marked by a slight depression than by a ridge or projection. Under the influence of weathering the carbonate gangue is dissolved, leaving behind a spongy residue of limonite and quartz. The cinnabar, though fragile, is chemically very stable, and where originally present in the lode may generally be found in the oxidized material at the surface. No evidence was obtained that indicated any considerable solution of the cinnabar or any downward enrichment of the lodes.

CLAIMS AND MINING DEVELOPMENT.

As already noted, the quicksilver deposits occur partly in the schist zone lying between the jasper zone on the northwest and a brown-slate zone on the southeast (see fig. 8) and partly in the southeast schist zone. The line of deposits between the jasper and brown slate may conveniently be referred to as the Maricopa County belt. That lying southeast of it may be designated the Gila County belt.

The claims along the Maricopa County belt were grouped at the time of visit as follows, the enumeration being from southwest to northeast:

Mining claims in Maricopa County belt.

Owner.	Number of claims.	Length along belt in feet.
Martin, Raymer & Hayden		1,500
Hayden & Allison	3 fractions.	400
Sunflower Cinnabar Mining Co	15	4,500
Raymer, Hayden & Martin	4	3,000
Bowman & Reynolds (Tatum or Lost Packer group)	6	3,000
Maricopa Quicksilver Mines Co	14	4,500
McDevitt	6	3,000
Bowman & Reynolds (Quicksilver King group)	8	4,500
		24,400

Overlapping at its southwest end the foregoing line of claims is the line of claims on the Gila County belt. At its southwest end, in Maricopa County, is the L and N group of six or seven claims belonging to Christopher Martin and others. The total length of this group along the belt was not definitely ascertained but is understood to be five claim lengths, or 7,500 feet. On this understanding the holdings along the Gila County belt are as follows:

Mining claims in Gila County belt.

Owner.	Number of claims.	Length along belt in feet.
C. Martin and others (L and N group)	7 (?)	7,500 (?)
Bowman & Reynolds (Gila County group)	14	16,500
H. Bowman	1	1,500
		25,500

Whether there is an interval between the claims of Martin and those of Bowman & Reynolds was not learned.

The claims of Bowman & Reynolds, enumerated in order along the lode from southwest to northeast, beginning southeast of Pine Mountain, are as follows: Mercury Sulphide No. 3, Bernice No. 1, Mercury Sulphide No. 1, Mercury Sulphide No. 2, North Star No. 1, North Star No. 2, Northern Light No. 1, and Mercury Sulphide Nos. 4, 5, 6, and 7. The end line between North Star No. 1 and North Star No. 2 lies along the bed of Gold Creek.

On the Martin, Raymer, & Hayden group and the Hayden & Allison group no development work has yet been attempted.

On the Sunflower group (fig. 9) two tunnels have been run nearly west under the Go By claim from the slope above the west fork of Sycamore Creek. The upper or No. 2 tunnel (fig. 10) is from 250 to

300 feet above the creek. It is a crosscut about 150 feet long. From the end of the crosscut a drift of about the same length has been run southwestward on the Packover lode. A drift about 100 feet long run from the north side of the crosscut is apparently not on the lode. The No. 4 tunnel is about 100 feet lower. This also is a crosscut and runs in the same direction as the upper tunnel. It is about 500 feet long and cuts the lode about 390 feet from the portal. A drift 50 to 60 feet long has been run on this lode, supposed to be the

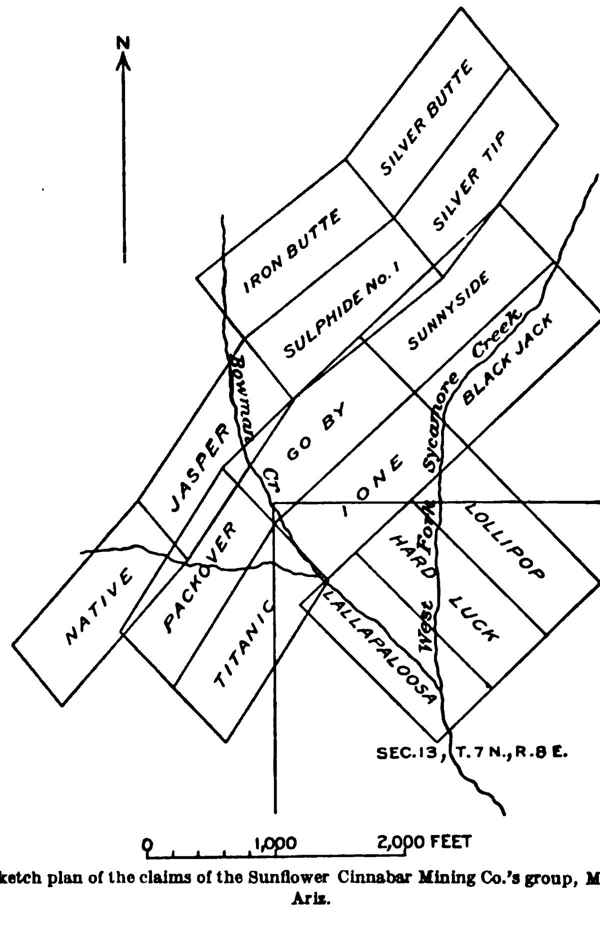


FIGURE 9.—Sketch plan of the claims of the Sunflower Cinnabar Mining Co.'s group, Maricopa County, Ariz.

Packover. Northeast of these tunnels a small open cut has been made on the Sunnyside claim and some cinnabar has been obtained from what is considered a continuation of the Packover lode.

On the Tatum group two tunnels have been run. The lower, reported to be at an altitude of about 4,900 feet, was not visited. It was said to be between 200 and 300 feet in length but had not at that time reached the lode. The upper tunnel, about 150 feet higher up the same hill, was about 235 feet long at the time of visit. It runs

S. 33° E. and crosscuts the schists, which here dip 60°–70° SE., whereas the prevailing dip in the district is to the northwest.

On the Maricopa group a crosscut tunnel at an elevation of about 4,900 feet has been run northwestward to cut a lode that outcrops about 2,000 feet higher up the hill, on the Lost Packer No. 8 claim. The length of this tunnel was not recorded at the time of visit but was probably between 200 and 300 feet. It had not reached the lode.

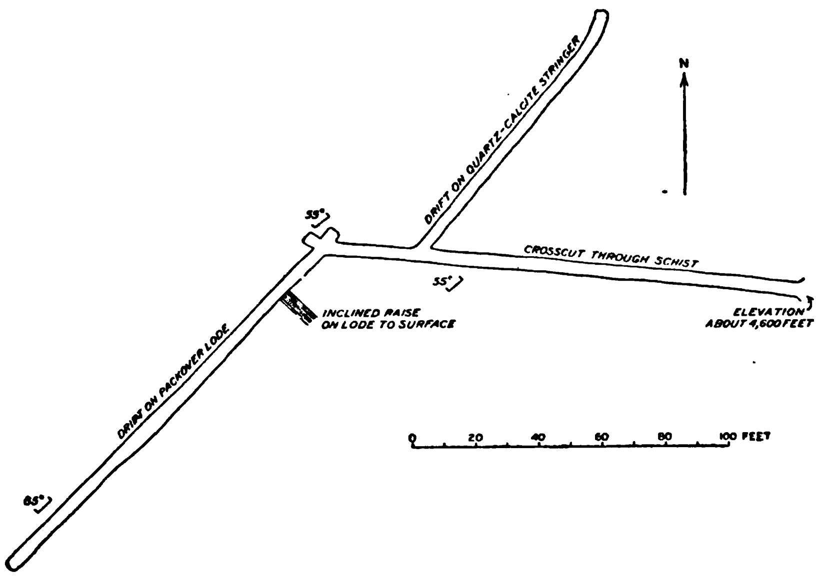


FIGURE 10.—Sketch plan of upper or No. 2 tunnel of the Sunflower workings, Maricopa County, Ariz.

Northeast of the Maricopa group the only workings on the quicksilver deposits at the time of visit were merely such shallow cuts and pits as fulfilled the requirements of the assessment provision of the mining law.

DESCRIPTIVE DETAILS.

The two tunnels of the Sunflower Cinnabar Mining Co. were both run so as to cut the Packover lode beneath a section of its outcrop where little or no cinnabar has been found. The lode where cut by the tunnel appears to have a width of about 12 inches, and the principal stringer, which is nearly 6 inches in maximum width, consists of buff ferruginous carbonate, white calcite, quartz, and cinnabar. An assay of a sample taken across a width of 7 inches of the lode at this point yielded Mr. Hutchinson 1.25 per cent of quicksilver. Of three samples taken by him from this tunnel the richest, representing a width of 5 inches, gave 3 per cent of quicksilver, indicating roughly, at the present high price (quotations in June, 1915, taken for convenience at $75 a flask of 75 pounds), $80 ore.

A few feet north of the crosscut the vein disappears. It is apparently cut off obliquely by a fault, but the displacement is probably not great. South of the crosscut the vein has been followed for about 100 feet to a point where the drift leaves the vein, which passes into the footwall.

The lode as seen in the lower tunnel is of the same general character as in the upper tunnel. For a part of its course at least it follows a layer of squeezed limestone in the schist. This layer is cut by irregular stringers of quartz and white calcite carrying more or less cinnabar. In places also paper-thin seams of cinnabar without gangue are fairly abundant in the schist. In the schist exposed in the crosscut tunnel a little cinnabar was noted for at least 50 feet west of the main drift. Here as elsewhere the lateral limits of the lode are indefinite.

A sample representing a width of 3 feet across the best part of the lode as exposed in the lower tunnel gave, according to Mr. Hutchinson, a little less than 2 per cent of quicksilver.

On the Sunnyside claim, about a thousand feet north of the tunnels, the Sunflower Cinnabar Mining Co. was obtaining ore for its retorts at the time of visit from a small open cut. Here was exposed a veinlet, measuring 3 inches in its widest part, of cinnabar and limonite lying in the planes of lamination of the schist. The veinlet was exposed with nearly maximum width at the northeast end of the cut and had been followed to a point where it pinched out to the southwest, in a distance of 6 feet. This is probably the largest and richest single veinlet seen. Mr. Hutchinson's report shows that it contains 38.2 per cent quicksilver, roughly $860 ore at present prices, but a 2-foot sample across the lode, with the stringer omitted, gave only 0.7 per cent, corresponding to $14 ore.

The upper tunnel of the Tatum group on the Lost Packer No. 1 claim cuts a stringer of ferruginous carbonate, quartz, and cinnabar 96 feet from its portal. A sample from this stringer, which, as exposed in the tunnel, is from 1 to 3 inches wide, carried 2.7 per cent of quicksilver, according to Mr. Hutchinson. At 150 feet from the portal the tunnel passes through a fairly strong gouge lying in the planes of schistosity and another similar gouge was noted about 195 feet from the portal. No cinnabar was seen in connection with these gouge-filled fissures. Since the tunnel was visited it has been reported that some cinnabar has been found in the "Tatum tunnel" about 115 feet from the portal. It is not clear whether the account received refers to the upper or lower tunnel. A small sample of this material sent to the Geological Survey by Dr. Burt Ogburn, of Phoenix, shows small veinlets of ferruginous brown carbonate, calcite, and quartz carrying cinnabar and little nests of specular hematite. As the material includes considerable limonite, it may perhaps have come from the upper tunnel or from some new opening.

On the Lost Packer No. 8 claim, of the Maricopa group, there is a strong outcrop, fully 2 feet wide, of quartz and silicified schist carrying a little cinnabar. The lode has the usual northeast-southwest strike and dips about 80° NW. It outcrops along the hillside at an elevation of about 5,100 feet and at the time of visit had not been cut by the crosscut tunnel, 200 feet lower. The quartzite outcrop is apparently local, the course of the lode being indicated elsewhere by a soft rusty zone in the schist. The belt of schist in which this lode occurs is the same as that which constitutes the country rock of the Sunflower Cinnabar Mining Co.'s deposits. It contains some lenses of limestone near the Maricopa tunnel.

On the L and N group some rich stringers of quartz and cinnabar up to an inch in width had been exposed at the time of visit by shallow prospecting pits, and a furnace with one retort was being built.[1] This lode lies southeast of the Maricopa lode, being separated from it by the southeast belt of brown slate and by a belt of conglomerate which in this part of the district appears to occupy the same position with relation to the other rock belts that the rhyolite porphyry does near the Sunflower camp.

On the Bowman & Reynolds Gila County group the most southwesterly opening at the time of visit was a small cut on the Bernice No. 1 claim. The country rock here is a gray-brown granular schist which retains distinct indications of an original clastic structure and is apparently a metamorphosed sandstone or grit. The cinnabar occurs with quartz in small stringers, the widest measuring 1 inch, and in rather sparsely dispersed small specks through the adjacent rock. A sample taken by Mr. Hutchinson across 2 feet of what appeared to be the most promising part of the lode gave him 1.4 per cent of quicksilver, equivalent to $28 ore. A dark dike of altered basaltic rock runs parallel with the lode a few feet to the northwest, following the structure of the schist.

About 800 feet northeast of the above cut, on the same lode and near the crest of the ridge between Cane and Gold creeks, a small shaft, 8 or 10 feet deep, has been sunk on the Sulphide No. 1 claim. The shaft disclosed some cinnabar, but none of the material can rank as ore.

On the Northern Light No. 1 claim a prospect cut exposes a veinlet of quartz, limonite, and cinnabar, in places as much as 6 inches wide. Mr. Hutchinson's sample of this stringer gave 1.1 per cent of quicksilver. Another sample from the same stringer, where from 1 to 3 inches wide, gave 2 per cent of quicksilver, and a sample across 4 feet of schist adjacent to the stringer gave a trace.

[1] Two flasks are reported to have been shipped in March, 1915.

On the Mercury Sulphide No. 5 the lode shows the same general character as on the claims to the southwest. A sample taken by Mr. Hutchinson across a width of 11 inches of croppings just above the location cut gave 3.3 per cent of quicksilver, corresponding to $66 ore.

OTHER DEPOSITS NEAR THE QUICKSILVER LODES.

North of Bowman's camp, in the area of schist lying northwest of the jasper belt, a prospect pit on ground belonging to Mr. Bowman shows arsenopyrite and a little vanadinite. Still farther north, in McFarlane Gulch, considerable prospecting has been done in the same schists on claims reported to belong to the Mormon Mining Co. Most of the work has been done on a nearly vertical vein striking north 55° east, or approximately parallel with the schist. A short tunnel has been run on this vein, but most of the development apparently was accomplished by a shaft, now caved, which was sunk near the creek. The vein as exposed near the surface is in some places 7 inches wide and consists of quartz, pyrite, possibly arsenopyrite, and bournonite. The remains of a small arrastre and some heaps of imperfectly roasted ore show that an attempt was made to work the vein for gold, possibly on the supposition that the bournonite was a gold telluride. A little galena was noted with the bournonite.

ORIGIN.

As regards the problem of the origin of the Mazatzal quicksilver deposits, the ascertainable geologic facts are not illuminating. The conditions under which quicksilver deposits occur the world over have established fairly well a genetic connection between them and volcanic activity. Owing to their mobility in solution, moreover, the constituents of such ores are, in accordance with theory and actual experience, deposited nearer the surface than most sulphide ores. Consequently, although the Mazatzal ores are in pre-Cambrian schist, it is not probable that they were formed in pre-Cambrian time. That supposition would imply that they were deep-seated portions of deposits from which the upper parts had been removed by prolonged erosion. All that is known of quicksilver deposits suggests that they do not form at depths so great as would be demanded by the supposition that the Mazatzal deposits are pre-Cambrian. It is more likely that the ore constituents were introduced at a much later time, when the surface as a whole did not differ by many hundreds of feet of eroded material from that of to-day. It is a reasonable conjecture that the cinnabar found its way into the schists in Tertiary time and that its deposition was merely one phase of the volcanic activity of that period. The deposits, however, are not obviously connected

with any particular igneous rock, and the question whether they are most closely related to the basaltic or andesitic lavas of the region must, for the present at least, remain unanswered.

ECONOMIC POSSIBILITIES.

Not enough mining work has been done at the time of visit to determine whether the quicksilver deposits of the Sunflower district are susceptible of profitable exploitation. The geologic facts of occurrence and the sampling by Mr. Hutchinson indicate that the parts of the lodes of minable dimensions now exposed to view carry no more than 3 to 4 per cent of quicksilver at the most, although exceptional stringers here or there which might be sorted out from the broken ore are of much higher grade. To obtain a 3 or 4 per cent product—that is, $60 to $80 ore at present prices—considerable sorting would have to be done, with rejection of three-fourths or more of the rock broken. The chances for obtaining considerable quantities of 2 per cent or $40 ore with only moderate sorting appear to be good.

When it is remembered that the New Idria mine [1] in California, the largest producer of quicksilver in the United States, has for some years been making substantial profits on ore from which 0.5 to 1 per cent of quicksilver is won, it is evident that the Mazatzal deposits have considerable promise. Although costs are probably lower in California than in Arizona the situation of the New Idria mine is comparable with that of the Arizona deposits in that the mine has a 60-mile wagon haul to the nearest railway. Mr. Hutchinson's sampling, while thoroughly reliable, was only preliminary to possible work and was rendered difficult by the lack of development. Before the deposits can be appraised at their probable value additional sampling will be necessary. This sampling should be directed particularly to the estimation of the probable available quantity of ore of the minimum grade that can be profitably worked without sorting. To what width, for example, can a lode be mined as a whole to get a 1 to 2 per cent ore and how much of such ore can reasonably be considered available?

Facts that promise well for future exploitation are the undoubted persistence of the lodes for long distances over the surface and the lack of any evidence of decrease of tenor with increase in depth. Too little has been done to prove that the lodes continue downward without diminution in quicksilver content, and it is generally recognized that quicksilver ores as a rule are not deposited at as great depth as some other ores. Lindgren [2] states that no quicksilver deposit has been worked to a depth of 2,000 feet below its outcrop. On the

[1] U. S. Geol. Survey Mineral Resources, 1911, pt. 1, pp. 902-903, 1912.
[2] Lindgren, Waldemar, Mineral deposits, p. 472, 1913.

other hand, the work already done on these deposits gives no foundation for a belief that the cinnabar is less abundant at moderate depth than near the surface.

The small quantity of quicksilver thus far produced has been obtained by simply retorting the ore as mined, enough lime being produced from the gangue to effect reduction to the metallic state. It was evident, however, at the time of visit that considerable quicksilver was being lost through the crudity of the operations. More efficient modes of treatment will have to be employed if the deposits are to be worked profitably for any length of time.

The present transportation facilities are very poor and any plan for profitably working these deposits will have to reckon with the long wagon haul to Phoenix, Mesa, or Globe.

It should be remembered that the conversions of assay percentage into value per ton as given in this paper are based on the present abnormally high price of quicksilver. They should be reduced by a third or half to correspond to a probable normal market price.

IRON-BEARING DEPOSITS IN BOSSIER, CADDO, AND WEBSTER PARISHES, LOUISIANA.

By ERNEST F. BURCHARD.

INTRODUCTION.

The bright-red soil and abundance of débris of limonite (hydrated iron oxide) in bowlders, slabs, and gravel on the summits and slopes of the hills in northwestern Louisiana have for many years given rise to the hope that at least some of the deposits of this useful mineral might eventually be found to be of value. In 1886–1888 Lawrence C. Johnson, of the United States Geological Survey, made a reconnaissance of northern Louisiana and eastern Texas, studying the stratigraphy and the outcrops of the iron-bearing beds. A brief report[1] on this work was issued in 1888, but it contained little discussion bearing on the commercial availability of the deposits, partly because at the time of Johnson's work only one railroad, the Vicksburg, Shreveport & Pacific, served the northern section of Louisiana, and had important iron-bearing deposits been noted they would for the most part have been too remote from transportation routes to be of economic value. The transportation situation is greatly changed now. Two lines running north and south, the Kansas City Southern and the Texas & Pacific, traverse Caddo Parish, passing through Shreveport; the St. Louis Southwestern Railway runs northward from Shreveport through Bossier Parish; and the Louisiana & Arkansas Railway runs northward from Minden through Webster Parish. (See fig. 11.) Several other lines connect Shreveport with the south, east, and west. In view of the increased facilities for transportation, which have brought most of the known deposits of limonite within 4 miles of a railroad, interest in their possibilities has been revived and requests have been made by the citizens of northwestern Louisiana that the iron-bearing deposits should be further examined by the United States Geological Survey. It should be stated here that since the work of Johnson several other geologists, including G. D. Harris, A. C. Veatch. and

[1] Johnson, L. C., The iron regions of northern Louisiana and east Texas: 50th Cong., 1st sess., House Ex. Doc. No. 195, 54 pp., 1888.

G. C. Matson, have made extensive studies in the region, for both the State and the Federal geological surveys, but these studies have had reference more particularly to the general and structural geology as affecting the distribution of petroleum and natural gas or underground water, and little special attention has been devoted to the iron-bearing deposits. An opportunity was presented for a reconnaissance of these deposits in connection with those of northeastern

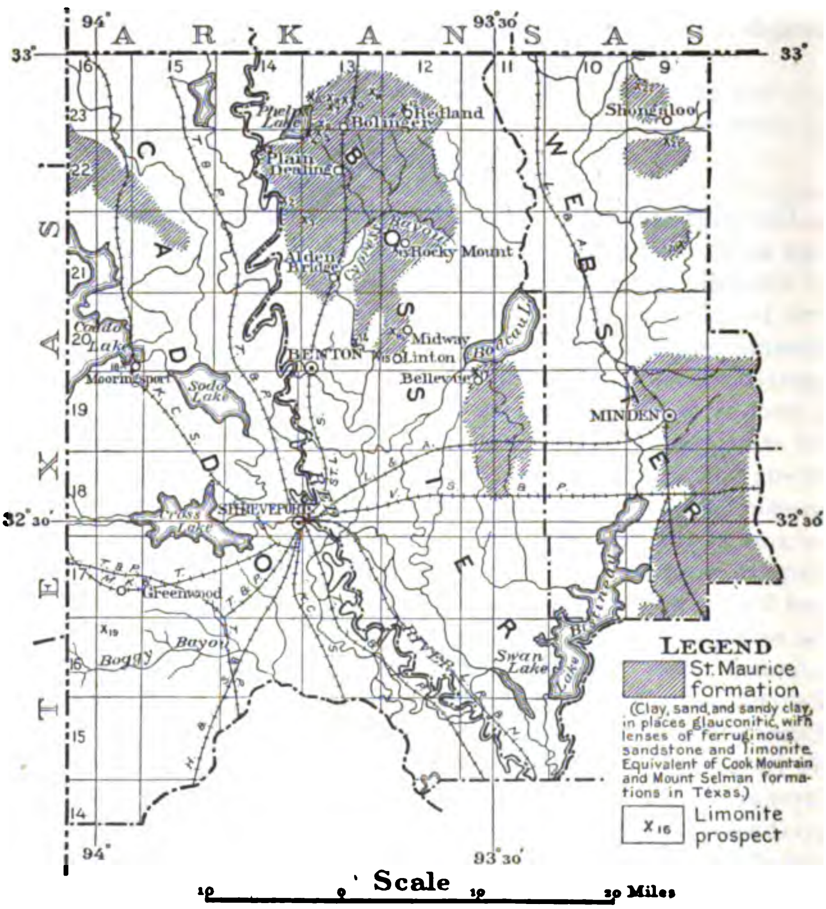


FIGURE 11.—Map of Bossier, Caddo, and Webster parishes, La., showing approximate location of limonite deposits examined.

Texas in the autumn of 1914, and accordingly the writer spent about two weeks in examining the most promising iron-bearing deposits in Bossier and Caddo parishes before proceeding to Texas. Although little encouragement could be offered as a result of these examinations, it was believed that more definite information would be yielded by prospecting in certain localities, and as the owners or trustees for these properties expressed a willingness to do the necessary prospect-

ing the localities were designated by the writer with suggestions for carrying out the work. After four weeks spent in a reconnaissance of the northeastern Texas field the writer returned to Shreveport in order to examine the results of the prospecting. At this time a trip was also made to Minden and northern Webster Parish.

The limonite deposits of northern Louisiana are by no means confined to the three parishes mentioned above. Johnson mentions the occurrence of limonite also in Bienville, Claiborne, De Soto, Jackson, Lincoln, Ouachita, Union, and Winn parishes, and the writer noted certain of these deposits in De Soto and Winn parishes. It is believed, however, that the deposits described in the following pages are typical, if not the best representatives, of the iron-bearing deposits in northern Louisiana. Johnson, who had opportunity to study the field as a whole, regarded Bossier Parish as one of the most promising districts of the iron-bearing region, and it is to-day even more certain that if the limonite deposits in general were of sufficient magnitude to be mined for iron ore those of Bossier Parish would be first to be drawn upon, as Shreveport would become the logical iron-manufacturing center. Therefore, if the most favorably situated deposits fail to meet the requirements of the iron industry there would seem little need to extend the investigation further. A comparison between the characteristic limonite deposits of northwestern Louisiana and the productive deposits of northern Alabama is given on page 150, under "Conclusions," in order that the disparity between them may be readily appreciated.

On page 109 will be found a bibliography of publications relating to the geology and iron-bearing deposits of northern Louisiana and northeastern Texas.

The writer thankfully acknowledges the courteous assistance of Mr. J. B. Babb, secretary of the Shreveport Chamber of Commerce; of the Bolinger Lumber Co.; and of Messrs. E. K. Smith, G. E. Gilmer, H. Kendall, and J. E. Whitworth, all of Shreveport, without which it would have been impossible to make the examinations in Bossier and Caddo parishes with economy of time and expense. To Messrs. A. D. Turner and J. J. Cahill, of Minden, thanks are due for courtesies in connection with the work in Webster Parish.

THE IRON-BEARING DEPOSITS.

CHARACTER.

The principal iron-bearing minerals in northwestern Louisiana are hydrated iron oxides, the most common of which is limonite, expressed by the formula $2Fe_2O_3.3H_2O$. Pure limonite contains approximately 59.8 per cent of metallic iron, 25.7 per cent of oxygen, and 14.5 per cent of water. Limonite is seldom found in an entirely

pure condition, generally containing more or less silica and alumina, intimately mixed with it in the form of sand and clay, and small percentages of manganese, phosphorus, and sulphur in certain chemical combinations, chiefly with oxygen. The presence of impurities reduces the percentage of metallic iron in limonite, so that the bulk of the commercial chemical analyses show only 45 to 55 per cent of iron.

The hydrated iron oxides are generally found near the surface and above ground-water level. Below the permanent level of ground water, where oxidation does not so readily take place, there may be found iron minerals which are not very stable when exposed to the atmosphere. Siderite (iron carbonate, $FeCO_3$) and pyrite (iron disulphide, FeS_2) are the most common of these minerals found in the clays and sands of northwestern Louisiana below the level of ground water. Both of these minerals become altered to limonite. In the deposits to be noted below siderite plays a very unimportant part, being noted in only one locality, where it occurs in an impure form known as "clay ironstone." Pyrite is rarely found near the surface. Where deposits of limonite or other iron-bearing minerals pure enough to be used for the manufacture of iron occur in quantities sufficient to render them of actual or potential value they may be termed iron ores.

The forms in which limonite and other hydrated oxides of iron occur in this region are varied but may be grouped under a few general types. Limonite is widely distributed in small quantities as a cementing material in sandstone, conglomerate, and breccia. Thus it may be found in all stages from a thin, soft crust in the sand, in which the iron hydroxide is visible only as a faint stain, to a massive, hard bed, in which the iron mineral appears to compose the major portion of the rock. To this type of deposits Johnson,[1] in his classification of the iron-bearing deposits of this region, has applied the general term "impregnation" deposits, from the fact that the iron hydroxide has been carried into the beds in solution. Such deposits are being formed at the present time, and instances will be cited farther on in this paper. Another common type of limonite is the nodular form, including concretions, geodes, and other modifications, such as are produced when a number of these forms are grown together into a honeycombed or cellular mass. Iron carbonate is most frequently found in nodules. Still another type is a more or less compact layer or bed of limonite that may have been formed in a bog. The deposit of this type may vary greatly in purity. They have been termed "lacustrine" by Johnson, but this term is misleading, for not all well-defined beds of limonite have been deposited in

[1] Johnson, L. C., op. cit., pp. 24–25.

bogs. Another type consists of limonite gravel, formed of the débris of former deposits at the same or higher levels. Gravel deposits are likely to be found on or near the tops of hills. In their general order of value these types might be summarized as follows, although local conditions may greatly influence the value of any particular deposit: (1) Nodular; (2) bedded; (3) gravel; (4) impregnation.

TOPOGRAPHIC RELATIONS.

The most conspicuous limonite deposits of Bossier, Caddo, and Webster parishes are situated on the plateaus and ridges that rise to heights of 100 to 300 feet above the low-water level of Red River, or 260 to 460 feet above sea level. In the northern part of Bossier Parish there is a crescent-shaped area of high red-surfaced land extending from Phelps Lake to and beyond Rocky Mount, and in the northern part of Webster Parish there is a corresponding high area east of Bodcau Lake. The higher lands of Caddo Parish are in the southwestern part of the parish. There are two horizons at which limonite is commonly found—one at or near the tops of the plateaus and ridges, the other near the top of a terrace-like area intermediate between the Red River valley and the highest levels.

GEOLOGIC RELATIONS.

The rock formations in which the limonite deposits of northwestern Louisiana occur are mostly unconsolidated sandy clay and sand, with a few beds of clay nearly free from sand and local indurated lenses of ferruginous sandstone. In the reconnaissance of the limonite deposits made by the writer there was small opportunity for study of the local geology and of course none for mapping the formation boundaries. Probably, however, all the beds with which the limonite deposits are associated in the area under consideration except those near Mooringsport (fig. 11, No. 18) may be assigned to the St. Maurice formation[1] of the Claiborne group (Eocene). Deussen[2] regards the St. Maurice as the equivalent of the Mount Selman and Cook Mountain formations, in which the limonite deposits of northeastern Texas are found. The Mooringsport beds are in the Wilcox formation, which underlies the Claiborne group.

A small collection of fossils was obtained by the writer from the lenticular bed of concretionary limonite in the wagon-road cut in the SE. ¼ sec. 25, T. 20 N., R. 13 W., Bossier Parish. These fossils have

[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, pp. 120–121, pl. 12, 1910.

[2] Deussen, Alexander, Geology and underground waters of the southeastern part of the Texas Coastal Plain: U. S. Geol. Survey Water-Supply Paper 335, p. 51, 1914.

been examined by William H. Dall, who reports as follows concerning them:

While none of the casts are sufficiently complete to enable me to be absolutely certain of the species, the ensemble is such that I feel there can be no great doubt that the horizon is lower Claiborne. The recognizable forms are Venericardia cf. *V. parva* Lea; Protocardia, probably *P. nicoleti* Conrad; Modiolaria sp.; Avicula cf. *A. clabornensis* Lea; Arca sp.; Leda cf. *L. catasarca* Dall; Leda cf. *L. acala* Dall; Corbula cf. *C. oniscus* Conrad; Ampullina? sp.; Volutilithes cf. *V. defrancei* Lea; and Pleurotoma cf. *P. sayi* Lea. This combination is unmistakably Eocene.

The bed yielding these fossils lies at the lower of the two limonite horizons mentioned above. The layers or deposits of limonite that simulate beds appear to be of small extent and are lenticular rather than tabular in form. They generally lie nearly flat but show noticeable dips in a few places. As rock dips in this region are of considerable significance to the petroleum geologist a caution should be inserted here against placing too much reliance on apparent dips in limonite layers. These layers are likely to develop along any irregular plane or zone within a bed of sand or sandy clay that affords a passage for iron-bearing solutions. Some cross-bedded sands afford favorable places for the deposition of limonite, with the result of imparting to the limonite seam, which stands out most conspicuously on weathering, a very misleading appearance so far as its relation to the dip of the local sediments is concerned.

DEPOSITS EXAMINED.

BOSSIER PARISH.

WEST OF PLAIN DEALING.

At a few points west and southwest of the town of Plain Dealing there are outcrops of limonite which have long attracted attention, Johnson having mentioned them in his report.[1] One of these outcrops shows two or three thin layers of nodular and concretionary limonite in a wagon-road cut on the south slope of a hill in the western part of sec. 6, T. 21 N., R. 13 W. (fig. 11, No. 1), about 5½ miles in an air line southwest of Plain Dealing. This is the place mentioned by Johnson as situated 2 miles south of Collinsburg, a town no longer in existence. The limonite appears to be of good quality, but not one of the layers is as much as a foot thick, and where all three are present their aggregate thickness is less than 2 feet. Johnson's detailed section is as follows:

[1] Johnson, L. C., op. cit., pp. 35–36.

Section 2 miles south of Collinsburg, La.

	Feet.
Sands and loam of higher ground	1–20
Clayey sands and sandy clays	1
Nodules of limonite	$\frac{1}{2}$
Clayey sand	2
Limonite in fine nodules	$\frac{1}{2}$
Clayey sand	4
Nodules of limonite	$\frac{5}{8}$–1
Reddish clay to depth unknown.	

If this limonite were concentrated into a single bed, close enough to the top of the hill so that stripping would not exceed 5 or 6 feet, and the bed were persistent throughout 300 acres or more, it would probably be of some value, for it lies within $3\frac{1}{2}$ miles of a railroad. None of these essential conditions are fulfilled, however. The layers appear to be lenticular and only local segregations of limonite in the inclosing clay and sand.

Other outcrops that attracted attention in early years are along the bluffs of Red River. On the slope above the low bluff south of the site of the old Gilmer landing, in the NE. $\frac{1}{4}$ sec. 35, T. 22 N., R. 14 W. (fig. 11, No. 2), are outcrops of two thin strata of concretionary and nodular limonite, each about 8 inches thick at the maximum, separated by about 10 feet of clay and sand. The débris from these strata produces a noticeable showing of limonite on the hill slope below the outcrops, giving the impression that thick beds are present, yet the débris itself is at most but a few inches thick, as is easily demonstrated by a pick. The quality of this limonite appears fair. The shells and septa are of clear dark-brown limonite, nearly free from sand, but ocher is present in the cavities of unbroken nodules. There are thin lenses of hard ferruginous sandstone in the formation in this locality. An analysis of the limonite is given on page 147 (No. 1).

About 4 miles north-northwest of the old Gilmer landing, near the mouth of the bayou which drains Phelps Lake, is a hill known as Millers Bluff in the western part of sec. 10, T. 22 N., R. 14 W. (fig. 11, No. 3). This bluff is now about a quarter of a mile from Red River, but the river, which changes its course considerably from time to time, is said to have flowed near the base of the bluff at the time of Johnson's visit, in 1886. A layer of concretionary limonite of good quality, 6 to 8 inches thick, crops out near the base of the hill a few feet above the flood plain. From 20 to 30 feet higher there is much débris of a very sandy limonite or ferruginous sandstone. Sandstone from this horizon is now being hauled from all available outcrops within a radius of 3 to 4 miles for use as riprap to prevent undermining of the banks of Red River at flood stage. Occasionally

bowlders of limonite are found and included with the sandstone, and this is probably the best use to which they can be put, for the deposits are too thin and scattered and too remote from a railroad (4 to 6 miles) to possess potential value as iron ore.

NEAR BOLINGER.

Northwest of the deposits just mentioned, mainly in the high country between Phelps Lake and the St. Louis Southwestern Railway, limonite in some form can be found on nearly every section of land. Some of the deposits have been known for 40 years or more, and others have been brought to notice through the extensive logging operations of the Bolinger Lumber Co.

In the NE. ¼ sec. 6, T. 22 N., R. 13 W., sandy limonite crops out in two prominent ledges just below the brow of the hill in a steep road that descends northwestward toward Phelps Lake (fig. 11, No. 4). These ledges are each about 1 foot thick, and at the top of one is about an inch of good limonite. The material, on the whole, is too siliceous to be regarded of value. In the adjoining portions of sec. 5, T. 22 N., R. 13 W., and sec. 32, T. 23 N., R. 13 W., particularly on the land of G. E. Gilmer, there are some of the best showings of limonite in Bossier Parish. On the Gilmer place much limonite débris is scattered about the surface of the fields that lie a few feet lower than the highest parts of the ridge. Piles of this fragmentary limonite in slabs 3 to 6 inches thick and up to 1 foot long have been gathered during cultivation of the fields, and some small fragments appear in the sandy fields on the highest parts of the place. In a creek bottom southwest of the farmhouse a bed of soft ferruginous sandstone and conglomerate is exposed for 100 feet or more. It is of very recent formation, and during wet seasons is evidently receiving ferric hydroxide from waters that percolate down from higher levels.

The best exposures of limonite on the Gilmer place are in two or three steep ravines in the northwest slope of the bluff facing Phelps Lake. The following two sections indicate the thickness and character of the limonite layers and their relations to the inclosing beds:

Section in ravine cutting bluff facing Phelps Lake in NW. ¼ sec. 5, T. 22 N., R. 13 W. (fig. 11, No. 5).

	Ft.	in.
Red sandy loam, with slabs and bowlders of limonite on the slope from top of plateau	5–8	0
Limonite, dark brown, of good quality, with mammillary surface and concretionary structure, but fairly free from cavities		9
Limonite, sandy		3–4
Red sandy loam and reddish soft sandstone, with a few scales of sandy limonite	4	0

	Ft.	in.
Limonite, light brown, sandy in places; weathers shaly and shows ocherous layers. Forms an overhanging ledge	1	4
Gray and red, slightly sandy clay, exposed for 15 to 20 feet, then covered and exposed only at two or three places	40	0
Hard bed of ferruginous sandstone and breccia, exposed to bottom of small pool. The fragments are mainly angular pieces of ferruginous sandstone	3	9
Concealed by wash of sand and clay	96	0
Grayish soft laminated sand	15	0
Flood-plain deposits of fine sand, silt, and organic matter.		

The next section was observed in a ravine about a quarter of a mile northeast of the point where the preceding section was measured, but it gives only the limonite-bearing sediments.

Section in ravine cutting bluff facing Phelps Lake in SW. ¼ sec. 32, T. 23 N., R 13 W. (fig. 11, No. 6).

	Ft.	in.
Sandy soil on slope	5	0
Limonite, dark brown, generally compact and lustrous		10–16
Slope concealed by soil, vegetation, and limonite débris	42	0
Limonite, dark brown, slightly concretionary, with mammillary top surface; contains much lustrous, rich limonite, but some sandy nodules and streaks, and a few inclusions of ocherous material	1	1
Sandy clay, in part concealed	18	0
Limonite in slabs 3 to 4 feet in length; top 7 inches of rich limonite with mammillary surface; lower half sandy. These slabs appear to be out of place and to have slumped down on their outer edges, owing to the undermining of the underlying soft beds. Possibly they may represent bed 4. (Compare analyses Nos. 3 and 4, p. 147)		10–14
Clay and sandy beds, mostly concealed	35	0
Conglomerate and breccia of ferruginous sandstone cemented by limonite. At the top is a layer, about 10 inches thick, of shaly limonite and ocher, apparently a replacement of sandy; shaly clay. Over the face of the bed where gullied out by wet-weather streams is a sheet of porous limonite in process of deposition from chalybeate seepage	4	0

Chemical analyses of beds 2, 4, and 6 are given on page 147 (Nos. 2, 3, 4). The coincidence between the analyses of beds 4 and 6 is also strong evidence that the slabs noted as bed 6 in the section have broken off from bed 4. The analyses indicate that the upper bed (No. 2) is of good quality, and if it were of sufficient thickness

(2 feet or more) and extended over an area of 200 acres or more, at a depth not exceeding 5 feet from the surface, it should possibly be able to compete with the limonite in Cass County, Tex. There are, however, nowhere any indications that this bed reaches a thickness much greater than that indicated in the exposures, nor is it likely that the areal extent, through which this excellence of quality is maintained will prove to be very great. In fact, at several other places where the corresponding bed is exposed it is much more siliceous. In a well in the E. ½ SE. ¼ sec. 31, T. 23 N., R. 13 W., near the points where the last two sections were made, hard rock was struck 10 feet below the surface and at intervals down to the bottom, at 32 feet. A fresh sample from a depth of 10 feet, which should correspond to the rich bed of limonite, is highly siliceous. Some prospecting for ore is reported to have been done on the Gilmer land. Although this work was not sufficiently thorough to yield definite results, further prospecting should be undertaken only with the understanding that the chances of success are slight.

In two abandoned lumber tramway cuts 1¼ miles west and 1¾ miles northwest of Bolinger there are showings of limonite. The only one worthy of mention is in the more distant cut, which is said to be in the SW. ¼ NW. ¼ sec. 28, T. 23 N., R. 13 W. (fig. 11, No. 7), on the Means place. A face of 9 or 10 feet shows about 7 feet of interstratified sand and limonite. The limonite occurs in streaks one-fourth to 1 inch thick and in concretionary layers 2 to 4 inches thick. Some of the sand is slightly glauconitic. If the material shown in the face of this cut were concentrated, the limonite, good and poor together, would probably not aggregate more than 20 per cent by volume. An analysis of a sample averaged from the limonite streaks and concretions and freed from sand and clay is given on page 147 (No. 6). The content of metallic iron, 43.21 per cent, is fair, although not quite as high as the general run of desirable brown ores, which average about 45 per cent. The silica, 19.15 per cent, considerably exceeds the average, and the alumina is a trifle high. The phosphorus and sulphur are both low. As the sample was taken with care to free it from sand and clay it is comparable to washed and screened ore, and it is not likely that a higher grade could be produced through commercial methods of concentration.

Another type of ferruginous deposit that has been noted with interest in the wooded country northwest of Bolinger crops out in the form of heavy ledges of dark-reddish rock on the hillsides or caps some knolls. This rock yields a bright-red powder, but examination with a field lens discloses the presence of a considerable percentage of sand grains, which are not readily visible to the unaided eye. These deposits would fall within Johnson's class of impregnation deposits and are found to grade within short distances into the fer-

ruginous conglomerate already mentioned. One of the most prominent exposures of this ferruginous sandstone is on the crest of a hill about half a mile east of Phelps Lake, at the northeast corner of the NW. ¼ SE. ¼ sec. 19, T. 23 N., R. 13 W., on land of J. C. Bolinger (fig. 11, No. 8). The ledge is 3 feet 9 inches to 4 feet thick and breaks off in large blocks weighing 5 to 10 tons each. The material here is fine grained and hard and gives a very red powder. There are some cavities in the rock filled with ocherous material. This deposit seems to be a local development. It lies practically flat and thins toward the south, as indicated on two hills within a quarter of a mile in that direction. Toward the southeast the bed merges into a conglomerate and breccia, and it appears in this form on the Lee place, in the SW. ¼ sec. 21, T. 23 N., R. 13 W. (fig. 11, No. 9). Here it is 1 foot to 1 foot 3 inches thick and is composed of small angular fragments of limonite and ferruginous sandstone, cemented together by limonite. A sample of the material from the heavy ledge on the Bolinger land, which is the richest deposit of this type to be noted, gave on analysis only 26.63 per cent of metallic iron.

A fairly thick slab of brown and yellow laminated limonite, more or less porous, was examined on the Honeycut place, reported to be in the SW. ¼ sec. 22, T. 23 N., R. 13 W. (fig. 11, No. 10). This slab is 1½ to 2 feet thick and is probably not in its original place, as it appears to have slumped down the side of a steep gully, where it lies about 75 feet below the top of the hill. Analysis of a sample that was averaged as well as possible from the exterior of this mass (p. 147, No. 8) shows it to contain 40.99 per cent of iron and 20.81 per cent of silica. The quality is therefore not sufficiently good to warrant its use as an ore.

The localities near Bolinger, mentioned above, are all from three-quarters of a mile to 3 miles west of the St. Louis Southwestern Railway. Several old tramway grades run through the woods, so that arrangements might easily be made for getting out ore if it should be found in the requisite quantity and quality.

East of the railroad limonite crops out at four or five places, but it appears to be of poor quality. In the NW. ¼ sec. 24, T. 23 N., R. 13 W., on the hills north of the Wyche place (fig. 11, No. 11), a heavy ferruginous sandstone, in places 2½ feet thick, caps the hills and forms much débris down the slopes. The material contains conglomerate and breccia and some limonite in streaks fairly free from sand, but on the whole it is leaner in iron than the rock sampled in sec. 19. Near Redland, which takes its name from the color of the soil, there is much limonite débris in the soil and surficial deposits. In the NE. ¼ sec. 29, T. 23 N., R. 12 W., outcroppings of a layer of limonite, good in some places, poor in others, and less than 1 foot

thick, were observed on the Keown place (fig. 11, No. 12). The well near the house, which passed through this limonite horizon, encountered only a thin layer of very sandy limonite.

ROCKY MOUNT.

Limonite occurs at several places between Redland and Rocky Mount, but nowhere in sufficient quantity to be of great importance. Johnson notes the occurrence of sandy ferruginous rock containing casts of Claiborne fossils in secs. 18 and 26, T. 22 N., R. 12 W., and of nodular limonite of good quality in sec. 29. Much ferruginous rock is exposed in the immediate vicinity of Rocky Mount, a relatively high point, which owes both its name and its altitude to the heavy beds of ferruginous sandstone which lie just below the surface of the highest ground and whose débris is scattered down the steep slopes. The chief occurrence of limonite at Rocky Mount mentioned by Johnson is in the clay sides of the cellar under Hughes's old storehouse. On investigation this material proved to be several thin plates of limonite, whose aggregate thickness does not exceed 4 or 5 inches, embedded in the clay. East of this old storehouse there is a good deal of residual débris on the surface. Along the road to Benton, just southwest of Rocky Mount, may be seen exposures of thin bands of ocherous limonite about 100 feet below the level of the high land. About 20 to 30 feet below the top of the hill a sandy layer of limonite less than 1 foot thick shows in the road, and the same layer crops out as a prominent ledge on the slopes of a wooded ravine east of the wagon road and about a quarter of a mile south of the store at Rocky Mount. Some parts of this bed are rich in limonite, other parts are coarse, pebbly cemented limonite, and in places the silica pebbles seem to have been replaced largely by limonite, so that altogether it is rather variable. In the graveyard, a quarter of a mile southeast of the store, much limonite has been thrown out of the excavations. Some is of good quality, but the greater part is sandy. There is a small knoll in Burke's field that stands about 15 feet above the rest of the plateau and is the highest ground at Rocky Mount. This knoll shows considerable débris of ocherous, more or less sandy limonite, representing the residue from a deposit that once lay still higher.

In the autumn of 1914 seven prospect pits, or wells, ranging from 6 to 17 feet in depth, and one trench, about 3 feet deep and 40 feet long, were dug on the rough land southwest of the cemetery, in the SW. ¼ sec. 17, T. 21 N., R. 12 W. (fig. 11, No. 13). The pits ranged from near the level of the plateau to a point low enough to give a fairly good section of about 40 feet of beds. The test pits and trench collectively show the following general section:

Section shown by prospect pits at Rocky Mount.

	Ft.	In.
1. Soil and limonite débris		1–2
2. Dark soil and roots		10–12
3. Reddish sandy clay with two to four seams of dark sandy limonite, one-fourth to one-half inch thick, coated with yellow sand that is sparingly glauconitic	6	0
4. Hard yellowish-red sand, slightly glauconitic	1±	
5. Dark hard sandy limonite (sand runs in pockets)		6–10
6. Yellowish-red sand, sparingly glauconitic, with two or three seams of sandy limonite about one-half inch thick	8	0
7. Sand, mostly silica, with some admixture of clay; color yellow, becoming lighter below	8	0
8. Sand similar to bed 7, becoming nearly white in lower part; carries a thin streak of sandy limonite	10–15	

The limonite found in the vicinity of Rocky Mount seems to be associated with sand that is sparingly glauconitic. The richness or leanness of the limonite in Bossier Parish seems to bear about the same relation to the abundance or scarcity of glauconite in the inclosing sands and clays as in northeastern Texas. A sample for analysis was averaged from layer No. 5 from the prospect trench, and the results are given on page 147 (No. 9). The small content of metallic iron, 36.86 per cent, together with 35.55 per cent of insoluble matter, shows that the material can not be regarded as an iron ore.

EAST OF BENTON.

The limonite deposits east of Benton lie mainly between Benton and Midway, at distances ranging from 3½ to 7 miles from the St. Louis Southwestern Railroad. Along the Benton-Midway wagon road about a quarter of a mile northeast of Big Cypress Bayou, in the SW. ¼ sec. 23, T. 20 N., R. 13 W. (fig. 11, No. 14), a layer of concretionary limonite is exposed in the ditches on both sides of the road. This layer shows a maximum thickness of about 1 foot 2 inches, but is interlaminated with shaly and ocherous material and in places grades downward into glauconitic sand. Two prospect holes were dug here. The upper one, which is about 8 feet deep, starts above the limonite horizon and probably does not go deep enough to penetrate it. This hole is in gray to yellowish-red shale with no streaks of limonite whatever. A second pit, about 4 feet deep, was dug in a "fill" of red clay, and although started at about the level of the limonite ledge it did not encounter any limonite. There are no indications of limonite in any of the roadside exposures for 15 feet above

and 10 feet below the ledge, and further prospecting should be discouraged. When the prospects wére examined the exposed portions of the limonite layer had become soaked by recent rains and appeared to be much more clayey and ocherous than when examined in dry weather.

In the SE. ¼ sec. 25, T. 20 N., R. 13 W., about 5 miles east-southeast of Benton and 1½ miles west of Linton, a layer of concretionary cavernous limonite crops out at intervals for 150 to 200 feet in the cut at the west side of the wagon road (fig. 11, No. 15). This layer is 12 to 19 inches thick and is overlain and underlain by clay. The limonite is light brown and shows little free silica, but contains much yellow ocher and reddish clay in the pockets and cavities. It is fossiliferous and yielded casts of a number of forms, mentioned on page 133, from which it has been concluded that the horizon is lower Claiborne. Three shallow test pits have been dug here, one of them on the opposite side of the road. The pits were started above the limonite and go below the horizon of the bed. The pit east of the road encountered fragments of low-grade ocherous limonite, perhaps the feather edge of the lens. One pit about 20 feet west of the road shows no ore, and one a few feet away from the exposure shows no increase in the thickness or improvement in the quality of the layer. This limonite when water-soaked shows the presence of clay and ocher more prominently than when dry. The clay for at least 30 feet above and below the limonite layer was carefully examined, and only one slightly ferruginous seam, about 25 feet below it, was found. The small quantity of limonite present here discourages further prospecting. A chemical analysis of a sample averaged from the layer at the point where the fossils were collected is given on page 147 (No. 10). This limonite is evidently of fairly good grade, for the percentage of metallic iron, 44.74, is close to the average of commercial limonites, and the impurities are not far above the normal. It is disappointing to find that the quantity is so small.

Thin layers of limonite were noted in several places along the Benton-Midway wagon road in the SE. ¼ sec. 18 and the SW. ¼ sec. 17, T. 20 N., R. 12 W., and in gullies on the old Belcher plantation north of this road (fig. 11, No. 16). This limonite is not more than 6 to 8 inches thick where exposed. It is concretionary, and apparently occurs at the same horizon as the layer in sec. 25, just described. At any rate the two layers are at the same altitude and are associated in a similar manner with clay, and above each on the highest ground a bed of light-gray fine sand overlies the clay. A chemical analysis of a sample of limonite from the Belcher place (see p. 147, No. 11) indicates a limonite of very good quality, which, if found in 2-foot to 3-foot beds, would be well worth prospecting to

determine its areal extent. Little encouragement toward finding any great quantity can be given, however, as a result of study of the local conditions.

BELLEVUE.

On the east slope of Bodcau Lake limonite sandy layers 1 inch to 2 or 3 inches thick appear in the wagon-road cuts in several places. Some half-formed concretionary masses occur in the sandy strata, the cementing material being a small percentage of iron oxide. Northwest of the site of the former town of Bellevue, in the NW. ¼ sec. 5, T. 19 N., R. 11 W. (fig. 11, No. 17), about 40 feet below the upland level, is a layer 6 to 8 inches thick of nodules, mostly of limonite but probably originally siderite. These nodules display interesting structure when broken open. They generally show septarian markings on the exterior and have large hollows in the interior, with relatively thin shells. The hollows are generally lined with corrugations and partitions of limonite that extend part way to the center, some of them as thin and sharp as a knife blade. Some are arranged in parallel bands around the circumference and at right angles to the exterior walls, but in some nodules they cross one another and form angular cells. Shrinkage cracks are also shown in the interior. Usually some powdery ocher or dry clay is found in the sealed cavity when the nodule is broken open, but in one nodule water and mud were found inside. While of interest from the viewpoint of the student of natural history these nodules or geodes of limonite are not present in sufficient quantity to be of commercial value. That they had attracted attention nearly 30 years ago is shown by the fact that Johnson mentioned them in his report.[1]

CADDO PARISH.

Only two localities were examined for iron minerals in Caddo Parish—near Mooringsport and about 3½ miles southwest of Greenwood. According to Johnson, who spent considerable time in this region, there are no other localities of interest in this connection in this parish.

MOORINGSPORT.

On the beach along the south shore of Caddo Lake half to three-quarters of a mile west of the Mooringsport station, in the northern parts of secs. 35 and 36, T. 20 N., R. 16 W. (fig. 11, No. 18), several layers of "clay ironstone," or impure iron carbonate, are exposed. They dip noticeably toward the southeast and have a total thickness of perhaps 2 feet in about four layers. The layers are formed of concretionary masses 3 to 8 inches thick and 2 to 3 feet in diameter. These masses are hard and brittle and are divided into septa, and

[1] Johnson, L. C., op. cit., p. 38.

their surfaces scale off concentrically. Along the septarian planes oxidation to limonite has taken place to a depth varying from that of a thin scale to more than half an inch. On weathered surfaces the limonite partitions stand out in relief above the checked surfaces of the concretions. Small concretions are oxidized through to the center. The unoxidized iron carbonate is gray, is faintly laminated, and contains minute sand grains. These sand grains are also discernible in the portions that have been oxidized to limonite. Only a faint effervescence is produced by dilute hydrochloric acid on the unweathered material. The specific gravity of this concretionary material is noticeably greater than that of limestone, which it resembles in appearance. Four oil pipe lines extend along the beach, and in leveling for them some of the clay ironstone has been dug out. In the low bluff that stands 15 to 25 feet above the beach two layers of concretionary sandy limonite 2½ inches apart are exposed, associated with calcareous shale. These layers are 3 to 7 inches thick and form the "ferruginous ledge" shown in a photograph by Harris.[1] This locality is near the Croom Clubhouse oil well No. 1.

The beach where the lower layer of concretions was noted is subject to floods. Caddo Lake was rather low at the time of visit, the stage being, according to local report, 161 feet above sea level, as compared with 174 feet for high-water stage. It is probable, therefore, that this layer, being covered by water part of the year, has not yet had time to become thoroughly oxidized.

At Mooringsport, both east and west of the Kansas City Southern Railway bridge, the "ferruginous ledge" may be traced for some distance along the lake bluff, about 10 feet below the top. The material is concretionary impure iron carbonate, altered on the surface to limonite, and becomes soft and shaly on weathering. The thickness does not exceed 7 inches. At the base of this bluff the lower layer has been dug into in leveling for the pipe lines. It was reported that several wagon loads of the iron carbonate and limonite from Mooringsport had been shipped to an iron furnace for analysis and test, but this report was not confirmed by records. It is certain that even if the tests proved favorable the quantity of iron-bearing material here is not sufficient for exploitation.

NEAR GREENWOOD.

About 3½ miles southwest of Greenwood the altitude of the hills forming the stream divides reaches about 300 feet in places, and on the higher points there are patches of very red loam containing débris of high-grade limonite. In the SW. ¼ sec. 3, T. 17 N., R. 16 W., on

[1] Harris, G. D., op. cit., pl. 13.

land of J. E. Whitworth (fig. 11, No. 19), there is a conspicuous showing of residual limonite. This material consists largely of gravel composed of fragments of the shells of geodes, but it contains also some whole geodes of limonite. The residual limonite mantles the top of the hill and extends down the north slope about 25 feet vertically. The thickness of the limonite gravel is not known, but it can be determined at little expense by means of a few test pits. The wagon road, which has been cut down a few feet and graded, does not show limonite in the roadbed, but in the roadside ditches there is more or less limonite within a foot or two of the surface and apparently parallel to the contour of the hill. The whole geodes range from 1½ to 6 or 8 inches in diameter. Some have thin shells, while others are nearly solid. Within the cavities is usually found a colored powder. In several geodes this powder is purplish and grades into the hard lining. In others the powder is gray or yellow, and in some it is coarse enough to be termed sand. Clay of various colors has also been found inside the geodes. The limonite composing the shells is generally of high grade. The shell and powder of one of these geodes were analyzed separately with the results given on page 147 (Nos. 12 and 13). The powder was purple and yielded 0.45 per cent of manganese. The shell of this geode proved to be the richest sample of limonite of all that were analyzed from northwestern Louisiana. It contained 50.61 per cent of metallic iron and only 9.85 per cent of insoluble matter and the other impurities were low. This analysis, it is of interest to note, coincides very closely with one published by Johnson, given on page 147 (No. 14), but he did not specify the locality further than that it came from Greenwood. It is doubtful whether there is much limonite in the immediate vicinity of Greenwood, for the altitude there is not as great as that of the observed horizons of residual material south of the town. Between the Whitworth land and Greenwood, at an altitude 100 feet lower than the residual limonite, a few crusts of sandy limonite, half an inch to 3 inches thick, crop out from sandy beds at the roadside, but these crusts carry a much lower percentage of iron than the sample analyzed.

As stated above, a few test pits should indicate the thickness attained by the residual limonite. If it is 4 or 5 feet or more, and the limonite débris constitutes one quarter or more of the volume of the surface material it should be worth while to extend the prospecting so as to determine the exact areal extent of the deposit. There is little probability of deposits being found here that would justify the extension of a railroad spur such a distance, and if ore is ever marketed it must be hauled by wagon or motor trucks to the railroad at Greenwood, down grade a good part of the distance.

WEBSTER PARISH.

NORTH OF MINDEN.

A hasty trip was made northeastward from Minden over the Lewisville road to and beyond Shongaloo, in the northern part of the parish. On the plateau 12 miles northeast of Minden and about 200 feet higher than the town, in the western part of sec. 14, T. 21 N., R. 9 W. (fig. 11, No. 20), there is a considerable spread of limonite in bowlders and gravel. This residual mantle appears to be about 1 foot thick and would yield a considerable quantity of limonite of good quality, but it is spread out too thin and is too far from a railroad at present to be of value.

Johnson[1] mentions the occurrence of a bed of recent conglomerate about 4 miles north of Minden from which a block was sent to the New Orleans exhibition of 1884–85. This conglomerate was said to contain about 26 per cent of metallic iron in the limonite cement. It contained quartz pebbles and angular fragments of sandstone and probably is analogous to the ferruginous conglomerate noted by the writer in the northern part of the parish.

NEAR SHONGALOO.

About 1 mile south of Indian Creek, west of the Lewisville road and 2 miles south of Shongaloo, on the W. H. H. Slack place, in the SW. ¼ sec. 3 and the SE. ¼ sec. 4, T. 22 N., R. 9 W. (fig. 11, No. 21), considerable ferruginous conglomerate is present. This conglomerate is found on the banks of small creeks and is forming to-day in the beds of the creeks. In places it is fairly rich in iron and carries only a moderate quantity of silica, but in others it contains pebbles of white quartz and chert. It could not possibly be utilized as an ore of iron.

On the James Roseberry place, in the SE. ¼ sec. 18, T. 23 N., R. 9 W., about 4 miles northwest of Shongaloo (fig. 11, No. 22), a bed of ferruginous conglomerate appears in the bed of a spring branch about 50 feet below the level of the high plateau. Some parts are rich in iron, but others contain quartz pebbles. It is reported that this bed was found to be about 4 feet thick in a prospect pit made about 1899. About 15 feet higher on the right bank of the creek a 7-foot prospect pit cuts through a reported thickness of about 2 feet of limonite. Part of the limonite from this bed is sandy, but 4 to 6 inches of it is rich in iron. There is no limonite here that could be mined profitably. An analysis of a sample of limonite from Allen Creek, near Shongaloo, published by Johnson, is given on page 147 (No. 15).

[1] Johnson, L. C., op. cit., pp. 40–41.

ANALYSES.

In the following table are arranged fifteen analyses of limonite from northwestern Louisiana—eleven being from Bossier Parish, three from Caddo Parish, and one from Webster Parish. Eleven of the samples were collected by the writer in the autumn of 1914 and four of the analyses are republished from the paper by Johnson already cited. Only the metallic iron was determined on sample No. 7. Most of these analyses have been discussed in the notes on the several localities from which the samples were derived. For convenience in comparison an analysis averaged from several hundred commercial analyses of washed brown ores produced in the Birmingham district, Ala., is given as No. 16 in the table. It is of interest to note that seven of the fifteen Louisiana limonites carried more than the Birmingham average of metallic iron, that three others nearly approached this average, and that if No. 7 is omitted the average of the remaining fourteen samples is 45.3 per cent of metallic iron, or a trifle higher than the Birmingham average.

Analyses of limonite from Bossier, Caddo, and Webster parishes, La., and from Birmingham district, Ala.

No.	Metallic iron.	Insoluble (practically SiO_2).	Al_2O_3.	Mn	P	S	Loss on ignition.
1	38.35	21.40	....	....	0.18	0.34	....
2	51.94	5.21	4.17	None.	1.15	.01	14.22
3	42.87	23.28	1.97	0.20	.93	.02	11.94
4	40.95	23.85	3.31	None.	.99	None.	11.34
5	49.97	12.15	....	....	.62	.08	....
6	43.21	19.15	4.51	None.	.26	.09	14.38
7	26.63	(a)	(a)	(a)	(a)	(a)	(a)
8	40.99	29.81	1.53	None.	.07	.06	10.90
9	36.86	35.55	2.23	None.	.24	.07	10.16
10	44.74	17.30	3.51	None.	.19	Trace.	16.71
11	48.92	13.16	2.77	None.	.16	.01	13.64
12	50.61	9.85	5.16	None.	.17	Trace.	13.64
13	48.67	19.97	1.09	.45	.41	.20	8.33
14	50.32	6.37	....	.079	Trace.	.100	10.26
15	45.72	18.72	....	.007	.247	.170	11.25
16	44.99	SiO_2 14.59	3.99	.74	.47	....	5.40

a Not determined.

1. From Millers Bluff, Bossier Parish. Cited by L. C. Johnson, op. cit., p. 36.
2. From SW. ¼ sec. 32, T. 23 N., R. 13 W., Bossier Parish, bed No. 2. Analyst, W. C. Wheeler, U. S. Geological Survey.
3. From SW. ¼ sec. 32, T. 23 N., R. 13 W., Bossier Parish, bed No. 4. Analyst, W. C. Wheeler, U. S. Geological Survey.
4. From SW. ¼ sec. 32, T. 23 N., R. 13 W., Bossier Parish, bed No. 6. Analyst, W. C. Wheeler, U. S. Geological Survey.
5. From SW. ¼ sec. 32, T. 23 N., R. 13 W., Bossier Parish (probably bed No. 2). Cited by L. C. Johnson, op. cit., p. 37.
6. From SW. ¼ NW. ¼ sec. 28, T. 23 N., R. 13 W., Bossier Parish (old tramway cut). Analyst, W. C. Wheeler, U. S. Geological Survey.
7. From NW. ¼ SE. ¼ sec. 19, T. 23 N., R. 13 W., Bossier Parish. Analyst, W. C. Wheeler, U. S. Geological Survey.
8. From SW. ¼ sec. 22, T. 23 N., R. 13 W., Bossier Parish. Analyst, W. C. Wheeler, U. S. Geological Survey.

9. From SW. ¼ sec. 17, T. 21 N., R. 12 W., Bossier Parish (Rocky Mount). Analyst, W. C. Wheeler, U. S. Geological Survey.

10. From SE. ¼ sec. 25, T. 20 N., R. 13 W., Bossier Parish. Analyst, W. C. Wheeler, U. S. Geological Survey.

11. From SE. ¼ sec. 18, T. 20 N., R. 12 W., Bossier Parish. Analyst, W. C. Wheeler, U. S. Geological Survey.

12. From SW. ¼ sec. 3, T. 17 N., R. 16 W., Caddo Parish, near Greenwood. Analyst, W. C. Wheeler, U. S. Geological Survey.

13. From SW. ¼ sec. 3, T. 17 N., R. 16 W. (powder from geode interior), Caddo Parish, near Greenwood. Analyst, W. C. Wheeler, U. S. Geological Survey.

14. From locality near Greenwood, Caddo Parish. Cited by L. C. Johnson, op. cit., p. 49.

15. From locality near Shongaloo, Webster Parish. Cited by L. C. Johnson, op. cit., p. 40.

16. From Woodstock and Champion areas, Birmingham district, Ala. Average of several hundred analyses of washed brown ore shipped to blast furnaces, 1906–1908.

LIMESTONE.

During the examination of limonite deposits in Bossier Parish the question arose whether supplies of limestone for flux would be available in case the limonite deposits should prove promising. Accordingly an examination was made of certain exposures of an impure grayish-blue limestone that occurs in the form of concretions embedded in the sandy clay near Red River west of Alden Bridge station. These concretions are exposed in ravines that lead down to the river and also in the river bluffs in the NW. ¼ sec. 35, T. 21 N., R. 14 W. They range in diameter generally from 6 to 18 inches, but in the bluffs of Red River they reach 5 or 6 feet. The concretions have septarian divisions along which they may be broken apart, and along these planes thin films of calcite are found. The larger the masses the more sandy they appear to be on weathered surfaces. No analyses are available showing the content of calcium carbonate, but when freshly broken the rock effervesces only slowly with dilute hydrochloric acid—an indication that the limestone is not pure, or else that it contains magnesia. As to quantity available, the concretions are not abundantly exposed, and not enough of this rock was seen in the brief reconnaissance to last a modern blast furnace one day; furthermore, under present conditions it would not be practicable to obtain limestone for flux from deposits where several hundred times as much dirt as stone would have to be removed. Limestone of similar character was noted by Johnson[1] at Carolina Bluff, on Red River 8 miles south of Collingsburg.

If limestone should be needed for flux in this locality, the most convenient places to obtain it would be where erosion has exposed the Cretaceous limestones in areas of structural domes. Such an area, where a limestone quarry has already been developed, is 5 miles west of Winnfield, La., where a much-fractured bluish-gray and white banded, irregularly crystalline limestone occurs. This rock contains

[1] Johnson, L. C., op. cit., p. 35.

considerable coarse crystalline calcite and has been locally termed marble. Minute crystals of barite ($BaSO_4$) have been deposited in open spaces on the calcite. Whether or not the presence of barite in minute quantities would effect the value of the limestone as a flux is a question. The following analysis of the stone by W. F. Hillebrand[1] shows its high degree of purity:

Analysis of limestone from Winnfield, La.

Insoluble	0.65	MgO	0.60
Al_2O_3	Trace.	CO_2	43.43
FeO	Trace.	SO_3	.27
MnO	.10	H_2O	.13
CaO	55.01		

Traces of barium, strontium, chlorine, and organic matter were also found.

CONCLUSIONS.

In the foregoing notes the endeavor has been to present for each deposit examined the facts that are essential to determine its commercial availability and to interpret these facts in the light of observations made on many deposits of brown iron ore in other districts of the South. In some of these districts considerable money has been spent in unprofitable prospecting for brown ore; in others much has been lost in attempting to mine deposits whose value had not been demonstrated by prospecting. In certain of these localities it was not possible to determine from a study of surface indications the true or probable conditions. In northwestern Louisiana, however, conditions are such that geologists should have no great difficulty in appraising the limonite deposits, and it is with regret that the writer is forced to the conclusion that these deposits offer no encouragement for development in the near future. If this conclusion prevents useless prospecting, the examination will not have been made in vain, although, of course, the result is disappointing to the community, which had hoped for the development of a local iron-ore industry.

The tabular summary on page 150 permits a rough quantitative comparison of the northwestern Louisiana limonite with the deposits that are being worked in northeastern Texas and at Russellville, Woodstock, and Champion, Ala.

[1] U. S. Geol. Survey Bull. 410, p. 194, 1910.

Summary of quantitative data of limonite deposits in northwestern Louisiana, northeastern Texas, and northern Alabama.

Locality.	Form of deposit.	Thickness.	Relative units of area.	Possible methods of working.
Northwestern Louisiana.	Residual limonite débris and soil.	Generally less than 1 foot.	Acres	By hand, if at all.
	Concretionary ledges	A few inches to 1½ feet.		
Northeastern Texas.	Residual limonite débris and soil.	A few inches to 5 feet.	Hundreds of acres.	By hand, and exceptionally by steam shovel.
	Concretionary ledges	A few inches to 6 feet.		
	Laminated beds	1 to 4 feet		
Russellville, Ala.	Residual limonite débris, sand, and gravel.	5 to 35 feet	Square miles	By steam shovel.
	Pockets of massive limonite.	10 to 25 feet		
Woodstock, Ala.	Residual limonite débris, sand, and gravel.	3 to 10 feet	do	Do.
	Pockets of massive limonite.	10 to 80 feet		
Champion, Ala.	Residual limonite débris, sand, and gravel. Pockets of massive limonite.	20 to 60 feet	Hundreds of acres.	Do.

A RECONNAISSANCE IN THE KOFA MOUNTAINS, ARIZONA.

By Edward L. Jones, Jr.

INTRODUCTION.

LOCATION.

The isolated mountainous area here designated the Kofa Mountains lies in the central part of Yuma County, Ariz. These mountains cover an area of approximately 200 square miles and are surrounded by broad, gently aggraded plains that separate them from other detached mountains, of which the Plomosa and Chocolate mountains and the Castle Dome Range are the nearest. The Kofa mining district, from which the mountains derive their name, is in the southern part of the range.

HISTORY.

Although southwestern Arizona had been prospected for many years, particularly in the early sixties, when the La Paz placers, 40 miles northwest of the Kofa Mountains, were actively worked, this area received little attention until the discovery of the King of Arizona ore body in 1896. The King of Arizona mine produced ore continuously from the date of its opening to the summer of 1910, when the ore became of too low grade for profitable treatment. The mine produced gold and silver bullion to the amount of $3,500,000, gold greatly predominating in value. The surface ore of the mine was extremely rich, much of it being worth $1 a pound. Ore of this grade was packed or hauled to Mohawk, on Gila River, and there treated in a small cyanide mill. In 1899 a 225-ton mill was built at the mine and was operated until the mine closed.

In 1906 the North Star ore body, 1½ miles north of the King of Arizona, was discovered by Felix Mayhew and sold shortly afterward to the Golden Star Mining Co. for $350,000. Development was soon started, and by 1908 this company had erected a cyanide mill which it operated until August, 1911, when the ore became of too low grade to work. The mine produced, according to statistics published by this Survey in Mineral Resources of the United States, approximately $1,100,000 in gold and silver. The deserted camp of Kofa centers around the King of Arizona mine, and the settlement of

Polaris about the North Star mine. The discovery of the North Star gave renewed impetus to prospecting in the Kofa Mountains, with the result that promising indications were found in their northern part and the small camp of Ocotillo was established. No ore has been shipped from the prospects near Ocotillo, and the development is as yet insufficient to show the extent of the deposits. One prospect has been developed to a depth of 300 feet, but with this exception the deposits are explored by shallow shafts and short tunnels, and at the present time assessment work only is being done.

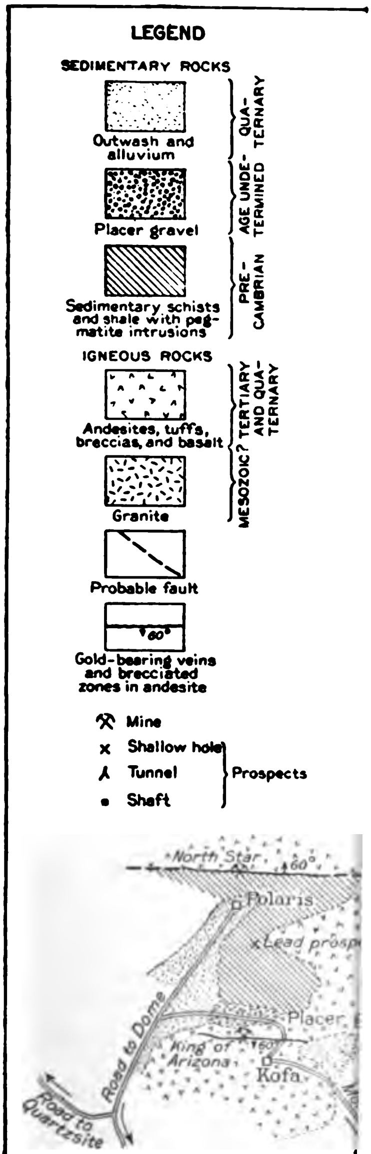
ACCESSIBILITY.

The supply and shipping point of the King of Arizona and North Star mines was Mohawk station, 45 miles distant on the Southern Pacific Railroad, but since the closing of the mines the southern part of the area is more accessible from Dome, 50 miles distant, where adequate transportation facilities may be had. In hot weather two full days are required to make the trip by team from Dome to the mines, but by automobile the time may be reduced to four hours. The railroad point nearest to the northern part of the area is Vicksburg, on the Atchison, Topeka & Santa Fe Railway, from which a fair but little-used wagon road runs south for 30 miles across the desert to Alamo Spring, at the head of a wash draining to the north. The road beyond the spring to Ocotillo and to other prospects in the northern part of the mountains is in poor condition and in many places is merely an ill-defined trail in the gulch bottoms. There are no roads directly connecting the northern and southern parts of the area, but on the La Posa plain, on the west side of the Kofa Mountains, a road from Quartzsite leads to Kofa and Polaris. (See fig. 12.)

The prospects in the northern part of the area were examined by the writer in April, 1914, during a 10 days' trip from Vicksburg in company with Mr. C. E. Zeigler. The King of Arizona and North Star mines were examined on a 2 days' trip from Dome. There are probably many small prospects scattered over the mountainous region that intervenes between the northern and southern parts of the area examined, but the uncertainty of the water supply and the shortness of the time allotted to this work prevented a more extensive reconnaissance.

The region is unsurveyed, the position of the mountains being indicated approximately on the Land Office map by hachures. The accompanying map (Pl. V) is based in part on a traverse line starting from the Cemitosa Tanks, extending to Ocotillo, and thence going southeastward to the Big Horn and adjoining prospects. The locations of the King of Arizona and North Star mines were projected from the Land Office map.

U. S. GEOLOGICAL SURVEY



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GEOGRAPHY.

The higher summits of the Kofa Mountains rise probably 2,000 feet above the surrounding plains, but many of the outlying knolls and mesas have a relief of a few hundred feet only. The Cemitosa Tanks, at the north end of the mountains, are approximately 1,900 feet in elevation, and Kofa, at the south end, is 1,700 feet. The mountains

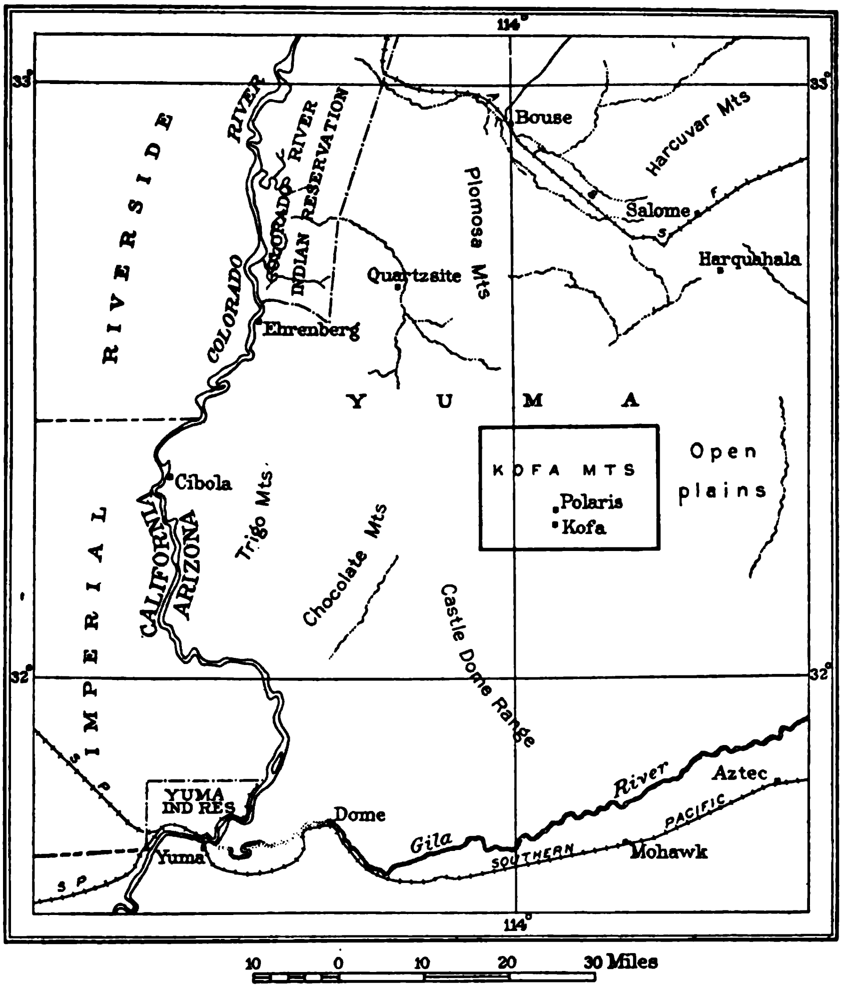


FIGURE 12.—Index map showing location of the Kofa Mountains, Ariz.

have no definite trend; they are composed of volcanic rocks that are intricately dissected into flat-topped mesas of small extent or into jagged spires and other fantastic erosional forms. Numerous sandy stream channels or "washes" radiate from the mountainous area to the surrounding plains, where their identity is completely lost. Rock waste deposited by these intermittent streams forms long, gentle

slopes extending out from the base of the mountains. Only rarely, during severe storms, do these channels carry surface waters, but here and there holes eroded in the bedrock, called "tanks," contain a small supply during certain months of the year. This source of water, however, is not to be depended on. Alamo Spring furnishes a small but constant flow of potable water. The water supply of the King of Arizona and North Star mines was obtained from wells reported to be 1,070 feet deep, sunk in the plain about 5 miles distant and 600 feet lower in elevation. The prospectors living in Ocotillo and other places remote from these sources collect during the brief rainy season such water as they can.

The climate of the region is extremely arid and the vegetation is scanty. In the washes are scattered mesquite and ironwood trees, and the hill slopes support several varieties of cactuses and small thorny shrubs. Such trees as exist are suitable only for fuel, and the supply in the vicinity of prospects is soon depleted.

GEOLOGY.

The Kofa Mountains are composed of extrusive igneous rocks which rest on an eroded surface of much older rocks. These older rocks are exposed in low foothills in the northern and southern parts of the mountainous area. The volcanic rocks are probably of Tertiary and Quaternary age. The older rocks consist of metamorphosed sediments with associated pegmatites, thought to be of pre-Cambrian age, intruded by granite and dike rocks of probable Mesozoic age.

VOLCANIC ROCKS.

Rhyolites and andesites with accompanying tuffs, breccias, and local thin beds of grit are overlain by olivine basalts which cap the mesas. The thickness of these volcanic rocks exposed in the Kofa Mountains is probably 2,000 feet. A light-colored thin fragmental rhyolite on the eroded surface of the older intrusive rocks was noted near the Cemitosa Tanks. Overlying it are thick flows of maroon to brownish andesites and associated tuffs and breccias. For the most part the flows are horizontal, but on some of the peaks light-colored tuff beds between layers of darker material dip at steep angles. Near the North Star mine flow bands in the andesite are well developed, but over most of the area examined the lavas give little indication of flow structure. The rhyolite tuff, of general light color, contains sparsely disseminated crystals of orthoclase, quartz, and biotite.

Andesites of gray, red, brown, and intermediate shades constitute a large part of the lava series. They vary in texture from fine-grained dense rocks with few phenocrysts to those having abundant phenocrysts. The phenocrysts are predominantly feldspar, mostly altered to calcite, but locally biotite is an abundant constituent of the rock.

Tests on some of the unaltered feldspars indicate that they have the composition of labradorite. The groundmass is a microcrystalline feldspar aggregate, colored with iron oxide. Olivine is a sparse though variable constituent of the andesites, becoming more abundant toward the top of the series. The occurrence of this mineral indicates a close relation, and possibly a gradation in composition, between the andesite and the overlying basalt.

The basalt flows are 300 feet or more thick in places. Although, as suggested, the lower flows appear to be closely related to the underlying andesites, the upper flows are made up of typical black vesicular basalt. This consists of a groundmass of calcic feldspar laths and augite grains inclosing large crystals of olivine, some of which show alteration to serpentine, inclosed by rims of iron oxide.

INTRUSIVE ROCKS.

An intrusive mass of granite exposed in a belt 1 mile wide occurs west of the Cemitosa Tanks. It is cut by diorite dikes, some of which are 100 feet wide. Between the King of Arizona and North Star mines narrow dikes of monzonite porphyry traverse the highly metamorphosed sediments and associated pegmatites. The intrusive rocks, though locally altered along shear zones, are not dynamically metamorphosed and are believed to be much younger than the metamorphosed sediments.

The granite is medium grained and is composed of quartz, feldspar, hornblende, and alteration products and a few accessory minerals. The feldspars consist of orthoclase and a perthitic intergrowth of orthoclase and albite. In some of the sections the feldspars are largely altered to sericite. Hornblende is a variable constituent of the rock, though nowhere abundant, and it is commonly altered to epidote and chlorite. Magnetite was noted as a secondary mineral in one of the sections.

No fresh specimens of diorite were obtained. The rock is coarsely granular, and large hornblende and calcic feldspar crystals are apparent to the eye.

The monzonite porphyry has a fine dark-gray groundmass, in which are numerous small feldspars and more sparsely distributed amphibole phenocrysts. The feldspars consist of orthoclase and broadly striated plagioclases, probably andesine, in about equal amount. The feldspars are altered in part to sericite and calcite. The amphibole is green in color and is partly altered to chlorite and calcite.

SEDIMENTARY ROCKS.

At the south end of the Kofa Mountains, between the North Star and King of Arizona mines, highly metamorphosed sediments crop out at the base of the lava flows and are the principal rocks of a

small ridge between these two points. A dark pyritiferous metamorphosed shale or slate forms the footwall of the North Star vein, and medium-grained quartzose biotite schists crop out on the ridge. Small irregular intrusions of pegmatite occur in these schists.

ORE DEPOSITS.

CLASSES.

The ore deposits of the Kofa Mountains consist of gold-bearing brecciated zones and veins in andesite, copper replacements along shear zones in granite, disseminated galena in monzonite porphyry dikes, and placer deposits. The deposits of the first group are regarded as of Tertiary age, and those of the second and third groups of probable Mesozoic age. The placer deposits have resulted from the disintegration of auriferous veins in the metamorphosed rocks.

GOLD DEPOSITS IN ANDESITE.

GENERAL CHARACTER.

Brecciated zones and veins in andesite were noted in the areas examined in the northern and southern parts of the Kofa Mountains, but only in the King of Arizona and North Star mines have ore bodies of economic importance been developed. These zones, with the exception of the North Star vein, trend from southeast to east, with southwesterly or southerly dips from 45° to vertical. The North Star vein trends east but dips 60° N. The zones vary from a few feet to 60 feet in width. Some are notably persistent along their strike; the North Star vein, it is said, can be traced for several miles, and the Geyser vein is traceable for 1½ miles. The vein matter consists of brecciated andesite, usually silicified and accompanied by stringers of calcite and quartz. Quartz commonly occurs as a pseudomorphic replacement of calcite. An examination with the microscope reveals adularia in the secondary quartz of the North Star vein, and this mineral was noted also in a specimen from the Geyser vein. Manganese occurs in these deposits contained in brownish calcite or as stains in the vein matter.

MINES AND PROSPECTS.

The King of Arizona and North Star mines are in the Kofa mining district, while the prospects in the northern part of the mountains, as judged from location notices of mining claims, are in the Alamo (unorganized) district.

KOFA DISTRICT.

KING OF ARIZONA MINE.

The King of Arizona mine is at the south end of the Kofa Mountains, in a small outlying group of hills, separated from another hilly area by a low saddle. The collar of the shaft is approximately 1,700 feet in

elevation, or about 200 feet above the surrounding plain and 200 feet below the highest point in this detached area. The property comprises four claims, on two of which ore has been developed. At the time of the writer's visit the mine had been closed for four years and the workings were in part inaccessible and generally in a bad state of repair below the 100-foot level. Mr. Eugene S. Ives, of Tucson, Ariz., kindly supplied notes regarding the value of ore and cost of treatment and other data, and Mr. R. M. Brighton gave information concerning methods of mill treatment. The mine is developed by an inclined shaft 750 feet deep, drifts at the 100-foot level, and an adit at the level of the collar of the shaft. The shaft is driven on the hanging-wall side a short distance south of the outcrop of the vein and approximately 100 feet lower. The drifts extend east and west and follow the vein; some of those to the west are over 2,000 feet long, but the drifts east of the shaft are not longer than 200 feet. A steam hoist in good condition is still in position at the shaft, but the cyanide mill is now dismantled.

The mineralized zone or lode trends between N. 60° W. and west and dips at an angle of 60° S. This zone can not be traced beyond the limits of the detached hill area. Its identity is lost a few hundred feet east of the mine shaft, but west of the shaft the vein is covered by two claims of the King of Arizona group, and it probably extends for a considerable distance beyond them. On the King of Arizona claims the vein is stoped out to the surface for 1,500 feet along its strike. The stoped areas are from a few feet to 30 feet wide and the ore body is said to average 12 feet in width. There is no mine dump, as all the material was run through the mill. The footwall of the vein is generally a well-defined slickensided plane, but the hanging wall is more indefinite. The ore body contained many small fissures and small slip planes, and most of them are parallel to the trend of the ore body, but several lie at angles with the vein, generally coming in from the hanging-wall side, and make horses of barren material. About 200 feet east of the shaft strong cross fissures filled with calcite apparently limit the ore, for development has not proceeded beyond this point.

The lode matter is a brecciated, generally brown to maroon andesite porphyry. The dense fine-grained groundmass contains altered white plagioclase feldspars and small, sparsely distributed, highly altered ferromagnesian minerals. The andesite is partly silicified, particularly where the fissuring is closely spaced. Stringers of quartz and calcite traverse the lode in all directions. They vary from those of knife-blade thickness to those several feet thick. The small veinlets are composed of quartz crystals, but in those 1 inch or more thick the walls are commonly lined with small quartz crystals and calcite occupies the middle. The calcite is brown to black in color and is highly

manganiferous. The lode matter is stained with iron and manganese oxides. The gold is said to occur free but in a very finely divided state. None was noted in the specimens collected from the vein and dump. The disintegration of the lode has produced no placer deposits.

The ore is valuable chiefly for its gold, but it also contains silver, the two metals being present in the ratio of approximately 58 to 1 in value. The ore at the surface was very rich, and many tons of it valued at $2,000 a ton was mined. The average tenor was $40 a ton. The metal content of the ore body steadily decreased with increasing depth until at the deepest workings, 750 feet below the surface, the gold and silver content averaged less than $3 a ton. At this figure the ore could not be treated profitably and the mine was closed. The walls of the ore body diverge with increasing depth, and Mr. Ives states that at the bottom of the shaft they are 80 feet apart.

The ore treatment was extremely simple, no complicated or expensive methods being necessary. After being dry-crushed through jaw crushers and rolls, to pass a 20 by 16 mesh, the ore was loaded into vats of 250-ton capacity and there leached with cyanide solution for a period of nine days. The strength of the solution was 4½ pounds cyanide to the ton of water. The gold and silver were precipitated in zinc boxes and the precipitate smelted into bars. The sands and slimes were not separated, as in ordinary cyanide practice, but notwithstanding this, the average extraction was reported to be 93 per cent. It is said that the cost of development work, stoping, and milling, including general expenses and taxes, amounted during the last few years of operations to about $2.80 a ton, and therefore material below $3 in assay value could not be treated profitably. The mill treated an average of 200 tons a day.

NORTH STAR MINE.

The North Star mine is near the base of a lava-capped mesa about 1½ miles north of the King of Arizona, at an elevation of approximately 2,000 feet. Between the outlying hill area in which the King of Arizona mine is located and the North Star there is much low-lying ground covered with outwash deposits.

The mine was operated by the Golden Star Mining Co., and development on the property was started in 1907, one year after its reported discovery. At this time a test lot of 17½ tons of ore from the surface yielded $9,774 in gold and silver. In August, 1908, a 50-ton cyanide and crushing plant had been installed and production had begun. Later the capacity of the mill was increased to 100 tons a day. The mine was closed in August, 1911, owing to a falling off in the metal content of the ore body and the high cost of ore treatment.

The mine is developed by two inclined shafts, No. 1 and No. 2, 90 and 500 feet deep, respectively, and by drifts and crosscuts on the vein at each 100-foot level. An adit from the footwall side connects with the first level from No. 2 shaft. The total length of development work is about 3,500 feet. The shaft is equipped with a steam hoist. The ore is treated in the combination amalgamation and cyanide mill after being reduced to sufficient fineness through crushers and rolls and finally in tube mills. The water supply was obtained like that of the King of Arizona—from wells over 1,000 feet deep in the desert plain about 5 miles south of the mine.

The ore body of the North Star mine is in a lode or vein of silicified andesite breccia and quartz which strikes east and dips about 60° N. The lode is 10 feet in average width at the North Star. It crops out several feet above the country rock, and from the mine it can plainly be seen extending for a considerable distance to the east and west. It is said that it can be traced for several miles and marks in a general way the base of the southern hills of the Kofa Mountains. At the mine the hanging wall is a pink flow-banded biotite andesite, and the footwall a dark calcareous shale or slate of probable pre-Cambrian age. The shale in places contains finely disseminated pyrite. The lode probably occurs along a fault.

The vein matter is of striking appearance. Near the surface angular fragments of the pink andesite, in places altered to green and gray tints, are cemented to an extremely hard rock by banded chalcedonic quartz, the bands being well shown by the deposition of minute crystals of sulphides, most if not all of which are pyrite. Pyrite also occurs disseminated sparingly through the altered andesite. Small vugs in this material are lined with sparkling quartz crystals. Under the microscope the chalcedonic quartz is seen to be accompanied by adularia in variable amounts, but nowhere in the slides examined in this mineral as abundant as the quartz. A green micaceous mineral is developed in the altered andesite, as well as a little chlorite and epidote.

The ore is valuable chiefly for its gold content, but it also contains small amounts of silver in about the ratio of its occurrence in the King of Arizona ore. The gold is said to occur free and very finely divided, associated with the fine sulphides in the chalcedonic quartz.

As interpreted from the assay chart of the mine, the high-grade ore bodies occur in shoots or chimneys which pitch to the east. They are of variable width, and the gold content deteriorates rapidly with increasing depth until at the fifth level the average tenor of the ore is below that required for its profitable treatment—$14 a ton. Assays in the drifts beyond the enriched parts of the lode show gold and silver in variable amounts, with a probable average value of $2 a ton. The surface ore of the North Star mine was of exceptionally high

grade. One streak of ore on the footwall was said to have been worth from $6 to $20 a pound, and ore to the value of thousands of dollars was stolen. The stoped-out parts of the ore bodies averaged 10 feet in width. No. 2 shaft was sunk on the lode in the approximate center of a shoot of high-grade ore over 500 feet long, the tenor of which exceeded $50 a ton. On the second level the high-grade ore occurs in several small shoots separated by ledge matter of relatively low grade. On the third, fourth, and fifth levels these shoots appear to have joined to form a shoot which is comparable in length to that of the first level, but which shows a rapidly decreasing metal content.

The ore of the North Star mine differs markedly from that of the King of Arizona mine in the absence of calcite and in the abundance of chalcedonic quartz and pyrite, factors which make it far less amenable to cyanidation. Several processes are necessary in order to reduce the ore to sufficient fineness to release the gold content. The cost of mining and milling is said to be $14 a ton. The disintegration of the North Star lode has produced no placer deposits.

ALAMO DISTRICT.

Brecciated zones in andesite in the northern part of the range have been prospected only in recent years, most of the location notices of claims being dated in 1908. As yet no large, rich ore shoot has been developed in any of these zones, but one prospect shows a high-grade ore streak, and encouraging results have been obtained from several others.

GEYSER PROSPECT.

The Geyser prospect, formerly known as the Silent King, is on one of several claims on a ledge of brecciated andesite porphyry near Ocotillo. The developments consist of an inclined shaft about 300 feet deep with short drifts and crosscuts on the 140-foot and 200-foot levels. The shaft is sunk at an angle of 45° on the hanging wall of the lode. The country rock in the vicinity of Ocotillo is predominantly a reddish andesite porphyry, with smaller masses of rhyolites and andesite tuffs and thin grit beds. The lode or brecciated zone in the andesite porphyry trends about N. 80° W. and dips 45° S. It can be traced for about 1½ miles, the I. X. L. prospect being located near its eastern extremity and the Rand near its western extremity. The lode ranges in width from a few feet to 60 feet on the Geyser claims, where for 2,000 feet it forms a prominent ledge, in places 30 feet high. The brecciated andesite porphyry is replaced by silica in varying amounts. In some places angular fragments 1 foot or more in diameter are replaced to form banded greenish rocks; in others small porphyry fragments are little altered. White, coarsely crystalline calcite occurs abundantly in the lode, particularly on the footwall, where there are many stringers and veinlets as much as 1 foot

wide. The lode near the hanging wall contains iron-stained kaolinized material in the numerous slips and seams and as the cementing substance of the breccia. Pseudomorphic quartz after lamellar calcite occurs in the hanging wall, and it indicates a deposition of calcite earlier than that deposited in the footwall.

The gold occurs free. It is more abundant along the hanging wall than along the footwall and is particularly associated with the iron-stained kaolinized material. A high-grade ore band of iron-stained breccia is several feet wide at the surface, but gradually thins out to a seam about 1 foot wide along a small fault plane at a depth of 90 feet, and it was not observed below the 140-foot level. A specimen of ore from the hanging wall on the 200-foot level shows abundant small particles of gold contained in a thin film of iron-stained kaolinized material enveloping a lamellar crystalline aggregate of pseudomorphic quartz after calcite. The average value of the ore from this prospect was not learned, but a small quantity of sorted ore is said to have assayed $140 a ton. No ore shipments have been made from the property.

RAND PROSPECT.

The Rand prospect is near the west end of the Geyser lode, which is about 5 feet wide and is prospected by a shallow shaft and a drift. The ore is a brecciated biotite andesite cemented principally by calcite, with some iron-stained material from which gold can be panned. The andesite fragments are dense and more or less silicified. They contain small nodules and veinlets of chalcedonic quartz, and small rust-stained cavities apparently result from the weathering of pyrite.

I. X. L. PROSPECT.

The I. X. L. prospect is near the east end of the Geyser lode. The developments consist of an inclined shaft 35 feet deep, driven on iron-stained breccia that is said to contain fine gold. Much of the lode matter is a breccia of small andesite fragments cemented by fine-grained secondary quartz. Calcite veins of later age, some of them 6 inches wide, cut this breccia. Under the microscope a thin section of the breccia shows a few adularia crystals in the secondary quartz.

REGAL GROUP.

The Regal claims are about a mile southeast of Ocotillo, and the workings are in a small hill on the south side of Red Raven Wash. Several brecciated zones and veins with east-west trend cross these claims and are developed by shallow shafts and tunnels. On the Regal No. 1 an inclined shaft about 35 feet deep is driven in iron-stained brecciated andesite porphyry. The zone is about 6 feet wide, trends N. 80° W., and dips 45° S. The zone is said to assay $8 a

ton in gold. On the Regal claim a 70-foot tunnel driven N. 10° E. into the hill, a winze 35 feet deep, and two short drifts constitute the development work. The country rock is andesite porphyry and gray tuff, cut by numerous veins and stringers of quartz and calcite, most of which have vertical dips. The largest calcite veins are 6 to 8 inches wide, and the winze was sunk on one of these veins. A short drift from the bottom of the winze intersects and follows for 20 feet a quartz vein about 1 foot wide. The quartz is porous and in places shows distinctly a pseudomorphic replacement of calcite. It is coated with an abundant manganese oxide residue, probably originally contained in the calcite. This material is said to yield gold on panning.

C. O. D. GROUP.

The C. O. D. group consists of several claims on a zone of brecciated red andesite porphyry which trends about N. 70° W. and crops out in several places along the course of Red Raven Wash. The brecciated zone is from 10 to 40 feet wide, is partly silicified, and in one place contains a calcite vein 3 feet wide. A shaft on one of the claims is probably 100 feet deep. The material on the dump consists of silicified andesite fragments, calcite, and gouge, but the tenor of the ore was not learned. Development on other claims of this group consists merely of shallow discovery holes.

CLAIMS SOUTHEAST OF OCOTILLO.

On the south and west sides of Red Raven Wash, about 7 miles southeast of Ocotillo, are 20 or more claims covering low hills that lie between high mesas to the west and the broad desert plain to the east. These claims are on the outcrops of numerous small brecciated zones and calcite and quartz veins in andesite and associated tuffs. The development work on most of them consists simply of shallow discovery holes and short tunnels, so that little could be learned of the continuity or character of these mineralized zones. The veins trend from northwest to west, and all have southerly dips. Mr. A. R. Gibson has submitted a sketch map of many of the claims surrounding the Big Horn and has indicated localities from which free gold can be panned, but no assays are available.

BIG HORN PROSPECT.

The workings of the Big Horn prospect consist of a tunnel 120 feet long which connects with a shaft 35 feet below the collar. The tunnel is driven N. 25° E. and cuts several small shear zones in the andesite porphyry stained with iron and manganese oxides. A shear zone several feet wide, with 2 inches of slickensided gouge, is exposed in the shaft. The country rock of andesite porphyry is gray, brown, or purple and contains abundant altered calcic feldspars in a dense

groundmass. Fine flake gold is said to have been found in the gouge material from these fissures.

CEMITOSA PROSPECT.

The Cemitosa prospect is in Cemitosa Wash, a short distance west of the Cemitosa Tanks. The workings consist of small discovery holes in a brecciated zone of andesite porphyry 10 feet wide. This zone trends N. 50° W., has a vertical dip, and can be traced for 1,500 feet along the westerly slope of a basalt-capped mesa north of the Cemitosa Tanks. The country rock is a reddish to brown andesite porphyry which apparently grades into the basalt capping of the mesa. The andesite at this point is probably a thin flow overlying granite, which is exposed at about the same elevation a short distance west and southwest of the tanks. The brecciated zone is iron-stained and contains numerous stringers of calcite, some of which are 1 foot wide. Part of the calcite is dark colored and it probably contains manganese. Fine colors of gold may be obtained from parts of this lode by careful panning, but the highest assay in gold reported from this prospect is $3 a ton.

COPPER DEPOSITS IN GRANITE.

GENERAL CHARACTER.

The copper deposits examined in this reconnaissance occur in the northern part of the Kofa Mountains along a shear zone in granite. The granite is exposed in an area of low relief in a zone over 1 mile wide west of the Cemitosa Tanks. Small knolls and mesas on the eroded surface of the granite are composed of quartzose breccias and tuffs and andesites. North of Cemitosa Wash the mesas are numerous and the area of granite is restricted to narrow belts in the arroyos, and to the south the granite is largely concealed by outwash deposits. The shear zone, which trends northwest, marks in a general way the western limit of the granite and probably represents a fault. Along this zone the granite is hydrothermally altered, and sericite, chlorite, epidote, and a greenish talcose mineral are prominently developed. A sheared basic dike consisting chiefly of altered pyroxene occurs in this zone and is associated with the copper mineralization of the Alamo group.

ALAMO GROUP.

The Alamo group consists of several claims along the western base of mesas north of a low divide at the head of Cemitosa Wash. The workings are all shallow holes or short drifts which explore the outcrop of the shear zone. Nearly all these workings show copper-stained rock and in some there are small irregular veins and seams of oxidized copper ores containing chrysocolla, malachite, and earthy oxides. The country rock of granite and basic dike rock is highly

altered and numerous slip planes are exposed in the workings. The development is insufficient to indicate fully the character of the deposit, and no ore body has yet been found.

ALONAH GROUP.

The Alonah group comprises several claims south of the road between the Cemitosa Tanks and Alamo Spring. The relief is low, and the outwash from the mesas to the west conceals much of the granite. The developments consist of shallow holes sunk in the sheared and altered granite, apparently along the same shear zone or fault on which the Alamo group is located. Along this zone the feldspar of the granite is in places completely sericitized and the ferromagnesian minerals are altered to chlorite and epidote. The mineralization has produced small seams and replacements of the sheared granite by oxidized copper minerals and disseminated magnetite, but the copper content is low. The development is entirely too superficial to show whether an ore body is present.

LEAD DEPOSITS IN MONZONITE PORPHYRY.

A dike of monzonite porphyry which cuts the pre-Cambrian metamorphic rocks crops out on a small ridge about a mile north of the King of Arizona mine. A short tunnel has been driven along a vein in the intrusive rock near the contact. No work was being done at the time of the writer's visit, and the tunnel could not be entered. The ore consists of a galena disseminated in a gangue of coarse fluorspar and calcite crystals. The tenor of the ore was not learned. This occurrence of galena is similar to deposits of economic importance in the Castle Dome Range, where the galena is separated from the gangue minerals fluorspar and calcite by dry concentration.

PLACER DEPOSITS.

The known placer deposits of the Kofa Mountains occur in a gulch draining westward north of the detached hills in which the King of Arizona mine is located. These placers have been worked for many years, and the total production is reported to be about $40,000 in gold nuggets. At present these placers are being worked in a small way, and a yearly production of several hundred dollars is reported. The gold occurs in outwash deposits which consist of bowlders and fragments from the metamorphic and volcanic rocks. The gold-bearing débris is said to be from a few feet to 70 feet deep over an area of approximately 60 acres. The gold is coarse and occurs near bedrock. It has evidently been derived from the disintegration of auriferous veins in the metamorphic rocks, as it is much coarser than that contained in the North Star and King of Arizona veins.

A RECONNAISSANCE OF THE COTTONWOOD-AMERICAN FORK MINING REGION, UTAH.

By B. S. Butler and G. F. Loughlin.

INTRODUCTION.

The data on which this report is based were obtained in the summer of 1912 during a reconnaissance of the mining districts of Utah made in a general study of the ore deposits of the State, and it was originally intended to publish the description in the general report, which is now nearing completion and which will include an account of the region herein described. Owing to the unusual interest now being shown in the region, however, it seems desirable to issue this description in advance of the report on the entire State.

The report is based on a reconnaissance quite insufficient to permit a thorough study of the very complicated geology, but the attempt was made to determine the main features of stratigraphy, structure, and ore deposition, and it is hoped that the results here presented will be of assistance to those engaged in mining. It should be borne in mind that both the descriptions and the map, though expressing the general features of the district, lack the detail desirable for the laying out of mining development. Such detail can be procured only by very careful mapping. A portion of the Park City district, mapped by Boutwell, Irving, and Woolsey, is shown on the map (Pl. VI) to indicate the relation of the region discussed to that district. The map of the Park City district as a whole is published in Professional Paper 77 of the Survey.

The Cottonwood-American Fork mining region includes the Big Cottonwood, Little Cottonwood, and American Fork districts, which are situated in the central part of the Wasatch Mountains just southwest of the Park City district. Its approximate limits are parallels 40° 30′ and 40° 40′ and meridians 111° 34′ and 111° 45′. Alta, the principal town, is centrally located, near the head of Little Cottonwood Canyon, about 20 miles southeast of Salt Lake City. Each of the three districts is named from a prominent canyon, which heads near the main divide and extends westward to the front of the range.

The districts are separated from one another by the divides bounding the canyons.

The Big Cottonwood district is the northernmost of the three and is reached in summer by automobile stage from Salt Lake City to Brighton (Silver Lake), a summer resort near the head of the canyon. Ore is hauled by wagon down the canyon to the smelters in Salt Lake Valley.

The Little Cottonwood district is between the other two and includes Alta, the principal settlement of the region, which is reached by stage from Sandy, 16 miles to the west, in Salt Lake Valley. Ore from most of the Little Cottonwood mines is conveyed by aerial tramway about 5 miles to Tanners Flat, and thence about 2 miles by wagon to Wasatch, the terminus of a spur line which connects with the Denver & Rio Grande Railroad at Midvale. The railroad follows the course of the old tramway, which was abandoned years ago.

The American Fork district, the southernmost of the three, is reached by wagon from the town of American Fork, on the Denver & Rio Grande and the San Pedro, Los Angeles & Salt Lake railroads. The town is about 20 miles from the more important mines, which are grouped near the head of the canyon. A stage has been operated intermittently between the town and the mining district. In the early days a railroad was built for a distance of about 16 miles up the canyon, but it was demolished in 1878 and its iron sold.

A few notes on the Alpine mining district, which lies about 5 miles north of the town of American Fork, west of the area shown on Plate VI, are given on pages 223–224.

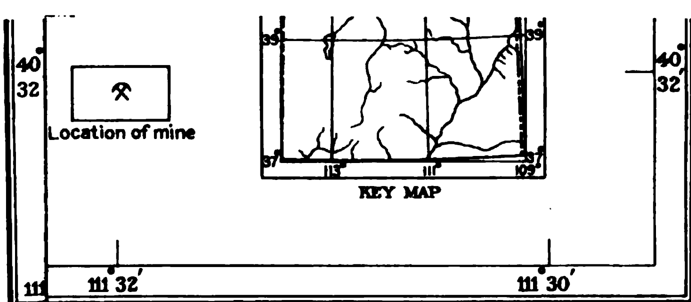
PREVIOUS WORK.

No detailed geologic work covering the entire region has ever been undertaken. The first geologic mapping was done by the geologists of the Fortieth Parallel Survey in 1869,[1] and their map, published in 1877, has been of great assistance to all engaged in the study of the region since that time. The general geology of the middle Wasatch Range was briefly described by Boutwell.[2] Descriptions of certain mines studied in 1880 were published in the report of the Tenth Census of the United States, extracts from which are quoted in the following pages. The glaciation of the region has been described by Atwood.[3] No recent study of the geology of the region as a whole was undertaken until the writers' reconnaissance in 1912. In that year a study of the stratigraphy and structure of the Cottonwood special quadrangle, which covers the area between the meridians 111° 34′

[1] U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 342–366, 1877.

[2] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah, with contributions by L. H. Woolsey: U. S. Geol. Survey Prof. Paper 77, p. 41, 1912.

[3] Atwood, W. W., Glaciation of the Uinta and Wasatch mountains: U. S. Geol. Survey Prof. Paper 61, 1909.



MINING REGION, UTAH

Geology of Little Cottonwood-American Fork region by B.S. Butler and G.F. Loughlin
Park City region by J.M. Boutwell, J.D. Irving, and L.H. Woolsey

and 111° 40′ shown on Plate VI, was made by F. F. Hintze, jr.[1] Hintze's results in part duplicate and in part supplement those of the writers. Additional confidence in the accuracy of the interpretation of the general stratigraphic and structural relations is felt from the fact that Hintze and the writers, studying the area independently, arrived at substantially the same conclusions.[2] Other papers which deal with certain features of the geology of the region are cited in the following pages.

Since the beginning of the recent activity in mining around Alta, several articles on the new developments have appeared in mining journals and newspapers. Among the more important of these are the following:

Ryan, G. H., The strike in the Cardiff: Salt Lake Mining Review, Nov. 30, 1914, p. 15. Describes the relation of the newly found ore body to local geologic structure.

——— Some Alta activities [special correspondence]: Eng. and Min. Jour., Apr. 17, 1915, pp. 689–690. Shows the replacement ore bodies along limestone-quartzite contact to be connected with ore-bearing fissures, and describes developments in the Cardiff, Columbus Extension, and South Hecla mines.

Howard, L. O., Mining in Utah: Min. [and Sci.] Press, Sept. 18, 1915, pp. 445–446. Describes conditions existing in the Big and Little Cottonwood districts, especially as regards the intrinsic value of mining shares. Accompanied by map showing claim boundaries of principal properties.

TOPOGRAPHY.

The region extends from the crest of the Wasatch Range to the edge of Salt Lake Valley and is therefore one of strong relief. The west base of the range has an approximate elevation of 5,000 feet, and the highest summits, between the upper parts of Little Cottonwood and American Fork canyons, attain altitudes of almost 11,500 feet above sea level. Alta, around which are located the principal mines in Little Cottonwood Canyon, is at an elevation of 8,700 feet and lies just north of Mount Baldy and Twin Peaks, the highest summits of the region. Brighton, or Silver Lake, also has an elevation of about 8,700 feet and is surrounded by summits attaining over 10,000 feet. Similar contrasts in elevation are found in the American Fork district.

The effects of recent glaciation are strongly expressed. The slopes are usually steep and smoothed; many of them include considerable areas of bare, polished rock, and others contain extensive deposits of drift that effectively conceal the bedrock geology. The canyons have the U shape, branch canyons are of the "hanging" type, and

[1] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 85–143, pls. 1–6, 1913.

[2] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, pp. 436–452, 1913.

the heads of canyons have the basin or cirque form—all characteristic of glaciated areas.

The region is one of considerable precipitation, including heavy snowfall which greatly interferes with winter operations. Since the removal of the timber, which was abundant in the early days, snowslides have been a menace to life and property. It is stated that in the Little Cottonwood district alone about 300 lives have been lost and much property destroyed as the result of snowslides.[1] At the higher elevations the snow remains until late in summer, and in years of especially heavy fall it may not entirely disappear before the snows of the next autumn begin to accumulate.

Water is abundant and of excellent quality. The creeks in the three main canyons furnish hydroelectric power which is used by several of the mines and is sufficient to supply any requirements of the mining region and of the neighboring towns in Salt Lake and Utah valleys.

GEOLOGY.

GENERAL FEATURES.

The formations of the Wasatch Range as a whole represent practically all the geologic periods from Archean to Tertiary. The sedimentary formations have a general northerly strike, and their prevailing dip is eastward, but they are affected by north-south folds, as in many of the ranges of western Utah, and in places by overthrust faults of moderate to great extent. Within the Cottonwood-American Fork region, however, the stratigraphic succession is present only in part and is interrupted by unconformities. The prevailing northerly trend of the formations is obliterated by a local doming around a prominent intrusive stock. The rocks have also been displaced by an overthrust fault, which appears to have been produced by pressure from the east, whereas those in northern Utah, southern Idaho, and southwestern Wyoming are attributed, in large part at least, to thrust from the west.[2]

SEDIMENTARY ROCKS.

Age.—The sedimentary formations within the Cottonwood-American Fork region are of pre-Cambrian, Cambrian, Devonian, Carboniferous and Triassic age. They may be divided into two main groups—the quartzite and shale series, of pre-Cambrian and Cambrian age—and the great limestone series, the "Wasatch limestone" of the

[1] Palmer, Leroy, Modern milling at Alta, Utah: Salt Lake Min. Rev., vol. 8, p. 17, 1906.

[2] Richards, R. W., and Mansfield, G. R., The Bannock overthrust: Jour. Geology, vol. 20, No. 8, pp. 681–709, 1912. Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 517–533, 1910.

Fortieth Parallel Survey geologists, which is mostly of Mississippian (lower Carboniferous) age, but also includes strata of Devonian, Cambrian, and in some places, perhaps, of other ages. Owing to the overthrust fault which has caused a part of the quartzite and shale series to override the lower limestone beds, the stratigraphic sequence in Little Cottonwood Canyon appears to be as follows: A thick basal series of quartzite and shale, a "lower limestone," an "upper quartzite," and the great upper limestone covered by later formations. The "lower limestone" and "upper quartzite" were called, respectively, the "Ute limestone" and the "Ogden quartzite" by the geologists of the Fortieth Parallel Survey, but the work of the writers and of Hintze has shown that these formations are not continuous throughout the region, also that the "lower limestone" contains Mississippian fossils, and, therefore, can not be the same as the Ute limestone, which is of Middle Cambrian age, whereas the topmost shaly beds of the "upper quartzite" contain fossils of Middle Cambrian age.

Pre-Cambrian rocks.—The pre-Cambrian rocks of the region consist of a series of quartzite, schist, and slate, or shale, about 11,000 feet thick. They make up the peaks north and south of Big Cottonwood Canyon and form the north boundary and part of the east boundary of the granodiorite stock along Little Cottonwood Canyon. Their strike is generally parallel to the granodiorite contact. They dip very steeply to the north, with numerous contortions, in the western part of Big Cottonwood Canyon, but the dip becomes less steep farther east and is as low as 30° along the divide northwest of Alta. The quartzite members of this series are prevailingly light gray, though some are reddish and purplish brown. The slate and shale members are black, drab, greenish, and purplish, and some of them have a strong slaty cleavage. Mud cracks and ripple marks are commonly present.

Near or at the top of the pre-Cambrian section is an unusual conglomeratic bed in which pebbles and bowlders are embedded in a very fine matrix. The character of this conglomerate strongly suggests that it is of ancient glacial origin, as suggested by Hintze, who has studied the rock in some detail.[1]

Cambrian quartzite and shale.—The Cambrian strata are separated from the pre-Cambrian by a slight angular unconformity, which is marked by a basal conglomerate. These strata include quartzite, shale, and limestone. The quartzite and shale band extends from a point north of Big Cottonwood Canyon southeastward to the upper part of American Fork canyon. In the area north and south of Alta it appears as two parallel bands, separated by a band of shale

[1] Hintze, F. F., jr., op. cit., pp. 99–101.

and limestone along the course of the overthrust fault. Southwestward from the head of American Fork the Cambrian quartzite and shale, as well as the pre-Cambrian strata, are cut off by the granodiorite intrusion. Along the lower half of American Fork Canyon and in the frontal hills east of Alpine the Cambrian quartzite is exposed at three localities, where small, faulted domal uplifts have brought it above the present surface.

The dip of the quartzite in the Big Cottonwood district is, as a rule, rather low (about 30°) eastward or northeastward, but just northwest of Alta and also near the American Fork divide it is locally steepened and contorted along two reverse faults, the more prominent of which extends along Superior Gulch. Just south of Alta, around Mount Baldy, the dip is unusually flat, owing to local warping along the west end of the Clayton Peak stock. South of the American Fork divide the dip is at a uniform low angle (15° to 20°) to the east-southeast.

The Cambrian quartzite as a whole is of very light gray color on fresh surfaces and yellowish on weathered surfaces. Its lower part contains many beds of fine conglomerate. Its upper part is thinner bedded than the average and grades upward into a dark sandy shale, which contains thin intercalated beds of quartzite and which in turn grades upward into the argillaceous limestone that forms the basal beds of the great limestone series.

In Big Cottonwood Canyon at two horizons in the shale Walcott[1] found Lower and Middle Cambrian fossils. In Little Cottonwood Canyon fossils were collected by the writers from the shale exposures a little south and east of the Flagstaff mine. On this collection L. D. Burling made the following report: "Contains Zacanthoides cf. *Z. spinosus* and *Obolus* (*Westonia*) *ella* and is almost certainly to be correlated with the Spence shale of the lower portion of the Middle Cambrian." Another collection was made at a horizon about 100 feet higher, of which Mr. Burling says, "Contains *Micromita* (*Iphidella*) *pennula* and is probably to be referred to the lower part of the Middle Cambrian." A collection was also made from the shale on the divide between Little Cottonwood and American Fork canyons. Of this Mr. Burling says, "Contains *Obolus* (*Westonia*) *ella* and is probably to be referred to the lower part of the Middle Cambrian, though this species is not very diagnostic."

The thickness of the Cambrian quartzite is given by Hintze[2] as 700 feet, and that of the overlying shale as 150 to 200 feet.

Cambrian limestone.—The limestone overlying the Lower and Middle Cambrian shale and having the same geographic extent

[1] Walcott, C. D., Correlation papers—Cambrian: U. S. Geol. Survey Bull. 81, p. 319, 1891.
[2] Hintze, F. F., jr., op. cit., pp. 103–104.

consists for the most part of shaly and dolomitic beds, the latter occurring mostly in the upper middle part. The following section of this limestone was measured by Hintze:[1]

Section of Cambrian limestone on Mill D South Fork.

	Feet.
Alternating blue shale and limestone conglomerate in beds 1 inch to 6 inches thick	10
Alternating shale and limestone, passing into shale	20
Thin fissile blue shale	6
Dark-blue thin-bedded limestones, partings exceedingly irregular	55
Dark-blue heavy-bedded limestone, with a wormy appearance, holes far apart	45
White limestone, thin bedded	10
Dark-blue wormy-looking limestone, greatly resembling typical bird's-eye limestone of the East	85
Thin-bedded brown shale, strongly jointed toward the top	60
Finely intercalated lime and shale	10
Light-blue streaky limestone; weathers white	15
Blue heavy-bedded limestone, with wormy appearance toward top	60
Brown shale; blocky appearance from extreme jointing	75
Blue limestone intercalated with seams of clay, giving a banded appearance	30
	481
Subformation: Alta shale	200

Hintze tentatively assigned this limestone to the Ordovician, but Burling,[2] in a more recent paper, states that he and F. B. Weeks found Middle Cambrian fossils in the type section of the limestone, at the south end of Reed and Benson Ridge. The limestone has a character typical of the Middle Cambrian in other parts of Utah, but its thickness, less than 500 feet, is much less than the thicknesses of other Middle Cambrian sections that have been measured in the State.

Unconformity at top of Middle Cambrian.—The oldest strata recognized in the Little Cottonwood district above the Middle Cambrian limestone, and resting in apparent conformity upon it, are of Lower Devonian age. The Upper Cambrian, Ordovician, and Silurian are therefore not present in this district and may be absent from the entire Cottonwood-American Fork region. The general uniformity of strike and dip and the lithologic similarity of beds at different horizons throughout the great limestone series prevent a

[1] Hintze, F. F., jr., op. cit., pp. 105–106.

[2] Burling, L. D., Early Cambrian stratigraphy in the North American Cordillera, with discussion of the Albertella and related faunas: Canada Geol. Survey Mus. Bull. 2, p. 101, 1914.

more positive statement until the series has been studied in great detail throughout the region.

Devonian limestone.—Devonian fossils in the region were first found by Tenney[1] in 1873. In 1912 fossils of this age were also found by Hintze[2] on Montreal Hill, a small area not traversed by either of the writers. Hintze's section is as follows:

Section of Devonian (Benson limestone) found on Mill D South Fork.

	Feet.
Hard dark-blue cherty coralline limestone	100
Massive dark-blue limestone	300
Fossiliferous blue limestone	3
Thick-bedded blue limestone	100
Dark-blue cherty and brecciated limestone	200
Dark-blue limestone	100
Dark porous limestone, very fossiliferous	21
Thick-bedded blue limestone, extensively bored	120
Thick-bedded light-blue limestone	43
Thin-bedded blue limestone	45
	1,032

The Devonian limestone is stated by Hintze to rest unconformably upon the Middle Cambrian limestone. Its base "is marked by a limestone conglomerate which rests upon a thin bed of yellowish-green shale, which in turn rests on a thick limestone member. This condition is best shown on the Reed and Benson Ridge, just above the old mine workings of the same name. It is also exposed on the ridge between Days Fork and Little Cottonwood Canyon, just west of Flagstaff Mountain." Hintze proposes the name Benson limestone to designate the Devonian strata.

These exposures suffice to show that the Devonian limestone is continuous to the northwest of Alta. It may well be present south of Alta also, but its extent in this part of the region is not known. In American Fork Canyon south of the Pacific (Blue Rock) mine, limestone of probable Mississippian age lies only a few hundred feet above the Middle Cambrian shale, and if any Devonian limestone is present at this place it will doubtless prove to be much thinner than the exposures northwest of Alta.

Mississippian limestone.—The Mississippian limestone is the most extensive limestone in the region, and stretches in a continuous broad belt from the hills north of Big Cottonwood Canyon to the southern limits of the region and several miles beyond. It forms a continuous eastward-dipping belt, except at Alta, where it is interrupted by the quartz diorite stock. Mississippian beds also form the uppermost part of the "lower limestone" at the head of Mill D South Fork.

[1] Tenney, Sanborn, On Devonian fossils in the Wasatch Mountains: Am. Jour. Sci., 3d ser., vol. 5, pp. 139–140, 1873.
[2] Hintze, F. F., jr., op. cit., pp. 108–113.

The lower beds consist of massive dark-blue limestone containing abundant fossils. The upper part is also of dark color and fossiliferous and is, in addition, characterized by prominent lenses and nodules of black chert. At or near the top of the cherty horizon is a light yellowish-gray limestone exposed on both sides of Mill D South Fork.

The following lots of fossils were identified by G. H. Girty, of the United States Geological Survey:

South end of "lower limestone" spur, head of Mill D South Fork:

Syringopora sp.	Syringothyris (?) sp.
Zaphrentis sp.	Composita sp.
Amplexus sp.	Cleiothyridina crassicardinalis.
Spirifer centronatus.	Euomphalus sp.

Mr. Girty states that the Madison (lower Mississippian) age of these fossils is highly probable.

West slope of Mill D South Fork, near crest of ridge, about a quarter of a mile north of the Carbonate mine:

Syringopora sp.	Spirifer centronatus.
Zaphrentis sp.	

Northern part of Reade and Benson Ridge, about one-tenth of a mile north of latitude 40° 38′. Bed just above light-gray limestone bed, at approximate base of intercalated limestone and quartzite horizon:
Spirifer centronatus.

These two lots are also stated by Mr. Girty to be of Madison age.

Above this light-gray bed is a considerable thickness of argillaceous limestone with intercalated beds of limy quartzite, which passes upward into the Weber quartzite. These intercalated beds have been noted by the writers along the northern part of Reed and Benson Ridge and along the narrow ridge just north of Ant Knolls, along the Wasatch County-Utah County boundary. The one fossil already listed as found in its lowest beds at the first-named locality determines its basal beds as within or just above the Madison limestone. The following fossils collected from the upper beds, at the small low knob just northwest of Ant Knolls, were determined by Mr. Girty as follows and assigned by him to the upper Mississippian:

Fenestella sp.	Martinia? sp.
Chonetes sp.	Composita sp.
Diaphragmus elegans.	Cliothyridina kirsuta.

According to Hintze,[1] a cream-colored sandstone 250 feet thick and overlain by 35 feet of brown and red shales is present in the middle of the Mississippian limestone section. These beds were not noted on the ground covered by the writers. Hintze states that the Mis-

[1] Hintze, F. F., jr., op. cit., p. 109.

sissippian has a total thickness of 940 feet and is overlain unconformably by the Weber quartzite, of Pennsylvanian age. The writers did not attempt to estimate the thickness of the Mississippian and gave practically no attention to formations of later age, beyond indicating their approximate locations on the map.

Post-Mississippian formations.—The post-Mississippian formations within the Cottonwood-American Fork region include the Weber quartzite, Park City formation, Thaynes formation, Ankareh shale, and Nugget sandstone. The Weber quartzite forms the slopes of Big Cottonwood Canyon and the summit of the ridge east of American Fork canyon. The Park City formation is mostly concealed by glacial drift and therefore is not separated on the map from the Weber quartzite. Its approximate position should be along the floor or lower east slope of Big Cottonwood Canyon from Brighton (Silver Lake) northwestward. The Thaynes formation extends along the northeast slope of Big Cottonwood Canyon, and the overlying Ankareh shale forms the crest of the ridge which marks the boundary between Salt Lake and Summit counties. The Nugget sandstone is exposed only in a small area at the north edge of the area mapped.

These formations are all more extensive and more important commercially in the Park City district, and full descriptions of them will be found in Boutwell's report on that district.[1]

IGNEOUS ROCKS.

The extensive east-west zone of intrusion of the central part of the Wasatch Mountains crosses the area under discussion. Within this area at the west is the Little Cottonwood stock of granodiorite, and at the east, extending from Alta into the Park City area, is the Clayton Peak stock of quartz diorite. These two main intrusive bodies are separated by about a mile of sedimentary rocks. The size and relation of these bodies can be best understood by reference to the accompanying map (Pl. VI). Although there is no surface connection between the two masses, the similarity of the rocks and the presence of numerous dikes of similar rock in the area between the two bodies make it seem very probable that they are of common origin and are connected beneath the surface.

As already mentioned, the sedimentary rocks are cut by numerous dikes of a porphyritic rock similar in composition to the intrusive masses and also by some much more siliceous dikes. A few small pegmatitic dikes were noted, and detailed study of the area may reveal other types of intrusive rocks.

[1] Boutwell, J. M., op. cit.

Little Cottonwood stock of granodiorite.—The Little Cottonwood intrusive body is composed of a rock of rather uniform composition. This stock was designated Archean by the geologists of the Fortieth Parallel Survey, but their interpretation was questioned by Geikie,[1] who pointed out features indicative of the intrusive relations of the rock. Its intrusive character was later verified by Emmons,[2] one of the Fortieth Parallel Survey geologists, who revisited the district in 1903. The interior of the stock has been exposed to a depth of at least 5,000 feet in Little Cottonwood Canyon, and so far as observed there is but little change in the rock from the portion adjacent to the intruded rocks to the deeper exposed portions of the mass. Typically it is a rock of granitic texture, locally porphyritic, with light-gray groundmass containing rather abundant dark minerals. Quartz, feldspar, hornblende, and biotite are readily recognized, and usually small yellowish-brown crystals of sphene can be detected. Under the microscope, in addition to the above-mentioned minerals, magnetite and apatite are seen to be rather abundant accessory minerals and a few crystals of zircon are noted. Both plagioclase and orthoclase feldspar are present, the former being far more abundant than the latter. The plagioclase is mostly oligoclase but scattered crystals as basic as andesine are present. Orthoclase and albite form micropegmatitic intergrowths, but such intergrowths are of small amount in the specimens examined. Biotite and hornblende are present in about equal amounts. Both are the common varieties.

A rather notable feature observed at numerous points is the presence of kidney-shaped portions distinctly darker than the main body of the rock. These range from a fraction of an inch to several inches in length and for the most part show a distinct gradation to the normal rock. In mineral constituents they are identical with the main rock, the difference being due to a relative increase in the amount of certain minerals, notably plagioclase, biotite, hornblende, and apatite and probably titanite and magnetite. The similarity in mineral constituents and the gradation to the main rock type suggest that these darker portions have resulted from a segregation of the more basic minerals during the process of crystallization. It may readily be imagined, however, that portions of the magma which had already crystallized were torn loose as the magma was intruded and disseminated through the mass, and that they were later partly dissolved and recrystallized and thus show now a gradation to the normal rock.

[1] Geikie, Archibald, Archean rocks of the Wahsatch Mountains: Am. Jour. Sci., 3d ser., vol. 19, pp. 363–367, 1880.

[2] Emmons, S. F., The Little Cottonwood granite body of the Wasatch Mountains: Am. Jour. Sci., 4th ser., vol. 16, pp. 139–147, 1903.

A chemical analysis of a specimen of the granodiorite collected near the wagon road about one-third of a mile below the power house in Little Cottonwood Canyon shows the following composition:

Analysis of granodiorite one-third of a mile below power house, Little Cottonwood Canyon.

[R. C. Wells, analyst.]

SiO_2	67.02	TiO_2	0.37
Al_2O_3	15.78	ZrO_2	.04
Fe_2O_3	1.56	CO_2	.00
FeO	2.18	P_2O_5	.26
MgO	1.09	S	.03
CaO	3.31	MnO	.02
Na_2O	3.85	BaO	.13
K_2O	3.67		
H_2O-	.29		100.23
H_2O+	.63		

No analyses of the hornblende and biotite of the rock are available, so that it is not possible to calculate the mineral composition accurately. From the chemical analyses and microscopic study it is believed that the following closely represents the mineral composition of the rock:

Approximate mineral composition of granodiorite, Little Cottonwood Canyon.

Quartz	20	Hornblende	7
Orthoclase molecule	20	Magnetite	2
Albite molecule	30	Titanite	1
Anorthite molecule	12	Apatite	½
Biotite	7		

Clayton Peak stock of quartz diorite.—The Clayton Peak mass of quartz diorite is very similar to the Little Cottonwood stock of granodiorite in its relations to the sedimentary rocks, though more linear in outline. The mineral constituents are the same, but in general quartz is less abundant and plagioclase and the dark minerals form a larger percentage of the rock. This mass extends into the Park City area and has been described by Boutwell and Woolsey.[1] It contains many dark inclusions, especially near the northern contact at the pass between Alta and Brighton (Silver Lake). Along the southern contact, due south of Brighton, a considerable body of darker augite-biotite diorite has separated from the main mass.

Quartz diorite porphyry dikes.—Numerous dikes cut the sedimentary rocks in the area between and around the two main intrusive masses and have been found throughout the area from its northern limit as far south as the Dutchman mine, in American Fork canyon. They vary considerably in appearance and doubtless

[1] Boutwell, J. M., op. cit., p. 75.

in composition. Commonly they are dark rocks with rather abundant phenocrysts of plagioclase, hornblende, and biotite in a groundmass of the same minerals, together with orthoclase and some quartz. In mineral constituents they are similar to both of the large intrusive bodies but for the most part, at least, are more basic than either. Some of the dikes are probably true diorite porphyries; others are of distinctly monzonitic character. Although none of these dikes were found to be directly connected with the main intrusive bodies, it is believed that they are offshoots from these larger bodies and are connected with them below the surface.

Granite porphyry dikes.—Dikes of granite porphyry were noted on the north side of Little Cottonwood Canyon. Such a dike is well exposed a short distance north of the Columbus Consolidated plant, where it can be traced for several hundred feet, striking several degrees north of east and apparently standing nearly vertical. Similar dike rocks were noted farther east in the direction of the strike of this dike.

The dikes are light fine-grained rocks containing scattered phenocrysts of quartz and feldspar and usually iron-stained cavities where some mineral has oxidized and been partly removed in solution. Under the microscope the phenocrysts are seen to be quartz, plagioclase, and orthoclase in a groundmass of quartz and orthoclase, the orthoclase forming a very large percentage of the rock. Sericitic muscovite is rather abundant as an alteration product of the feldspars.

Aplitic and pegmatite dikes.—Aplitic dikes are numerous, and a few of pegmatite were noted. A small vein of pyroxene and quartz is associated with one of the small aplitic dikes on the slope northwest of the pass between Silver Lake and Snake Creek. The pyroxene occurs in dark greenish-black crystals as much as 1 inch in length and is near diopside in character. Some crystals are partly altered to a greenish-gray fibrous amphibole. The aplite also contains similar crystals of fibrous or multiple-twinned amphibole. This vein, though small, is of interest as an indication that the mineralizing agents which developed diopside and associated minerals in the limestone at the contact near by were also active within the granite, where they represented the latest phase of the intrusion.

STRUCTURE.

The structure of the district is complex, and detailed mapping is necessary to work it out with the accuracy desirable for the direction of mining operations. Notes on the general relations are presented below, and it is hoped that they will prove of assistance in working out the detailed structural relations at the individual mines.

FOLDING.

The north-south folds that were apparently one of the earliest structural developments of this general region are not conspicuous in the Cottonwood area; at least their importance has not been recognized in the reconnaissance work. The area has, however, been affected by minor folding, which was a result of faulting.

OVERTHRUST FAULTING.

The earliest important structural disturbance in this part of the range seems to have been overthrust faulting. It is possible that this was contemporaneous with the folding farther east.[1] The main thrust fault extends along an irregular but generally north-northwest course and has been traced from the vicinity of Big Cottonwood Creek to the head of American Fork Canyon, where is disappears among a complex of reverse and normal faults.

South of Little Cottonwood Canyon it is well seen on both the east and west sides of the Mount Baldy mass, where several hundred feet of the great limestone has been overridden by Cambrian quartzite and shale. It is shown similarly north of the canyon, especially just east of Superior Gulch, and has been traced over the divide into Mill D South Fork as far as the north-south ridge south of the Carbonate mine. Its course is marked by the contact between the "lower limestone" and "upper quartzite" as far as Vena Flat, beyond which the "upper quartzite" overlaps on the main or "lower quartzite."

The amount of the overthrust has not been determined, but is considerable. The Cambrian strata are considerably above their normal position in the vicinity of the Alta Consolidated mine. Whether the position of the strata at this locality is due wholly to the overthrust faulting or in part to later faulting and the effects of intrusion has not been determined. The shale beds within the "upper quartzite" and between it and the great limestone series were most complexly folded, crumpled, and faulted during the overthrust movement. This result is especially well shown on the south slope of Flagstaff Mountain above the Columbus Consolidated mine. The movement on the fault was apparently from the east toward the west, and at the time of the faulting the plane probably had a rather gentle eastward dip that was increased by later movements.

Owing to the unknown extent of the overthrust and the irregularity of its contact, the depth and extent of the "lower limestone" east of its outcrop can not be closely calculated, a fact to be borne

[1] Hintze, F. F., jr., op. cit., p. 185.

in mind by companies planning to prospect the "lower limestone" at depth. Whether or not the "lower limestone" exists east and south of its outcrop at the head of the American Fork canyon can not be proved until the complex of faults there has been thoroughly worked out. From the meager evidence at hand it seems probable that the overthrust dies out in this vicinity and that the existence of the "lower limestone" in the American Fork country is improbable. (See section B–B′, Pl. VI.)

STRUCTURES FORMED DURING THE INTRUSION OF THE IGNEOUS BODIES.

Doming.—The igneous material that forms the Little Cottonwood and Clayton Peak masses, on being forced into the sedimentary series, in part broke across the strata and in part raised the overlying beds, forming a broad dome in which the sedimentary beds dip away from the intrusive rock. The doming is especially well shown around the Little Cottonwood mass, where the sedimentary formations crop out in concentric semielliptical form around the north and east boundaries of the intrusive mass. On the south the granodiorite broke completely through both the pre-Cambrian and Cambrian quartzites and is now exposed in contact with the great limestone series, which also dips radially away from the intrusive rock. On the west the dome structure is partly preserved but is mostly cut off by the great Wasatch fault. The small faulted domes along the lower part of American Fork canyon and east of Alpine may have been caused by the upward thrust of minor intrusive bodies connected with the granodiorite mass.

The same relation is true in a general way for the Clayton Peak body of quartz diorite east of Alta. The doming effect of the Little Cottonwood mass of granodiorite, however, was much more pronounced and conceals that of the Clayton Peak body except at the west contact of the latter south of Alta, where the eastward-dipping overthrust plane has been bent upward into a faulted synclinal attitude.

Reverse faulting.—In addition to the general doming of the sedimentary rocks adjacent to the intrusive bodies, the strata in places have been broken and thrust upward and outward from the intrusives, reverse faults being produced. The best exposed of these reverse faults is that in Superior Gulch, where the quartzites have been thrust up in contact with the overlying limestone. (See section A–A′, Pl. VI.) A smaller one is exposed along the quartzite, shale, and limestone contact at the south end of Reed and Benson Ridge. Similar faults were observed to the south, near the American Fork divide, and others are probably present in the

area. Those recognized have a concentric arrangement with respect to the intrusive granodiorite.

Mineralized fissures and faults.—The mineralized and other closely related fissures also appear to have been formed during or just after the intrusion of the main bodies. Those noted in the Mill D South Fork area, in the Cardiff and Branborg mines, strike about N. 35° E. and dip 60°–65° NW. The Silver King fissure zone of the Branborg mine can be followed southwestward through the quartzite and down into the granodiorite of Little Cottonwood canyon. The mineralized fissures in the principal mines around Alta strike N. 60°–70° E., in general parallel to the trend of the quartz diorite body, and dip rather steeply (60°–65°) to the north. Those in the American Fork district, so far as seen, appear to belong to two systems, one of northeasterly and one of about easterly trend. The stopes of the famous Miller mine lie in both directions, though the longest stope extends about N. 85° E. The Live Yankee also has veins in both directions. The Pacific and Dutchman veins belong to the northeasterly system. In the Barry-Coxe mine, on the north slope of the pass between Brighton and Park City, the mineralized fissures strike about north and east. The northerly fissures are the more heavily mineralized. These fissures lie at right angles to and parallel to the north boundary of the Clayton Peak body of quartz diorite.

Prominent barren fissures were noted following both the northeasterly and the easterly direction, and some with northwesterly trends were also seen.

The porphyry dikes follow the same general directions as the mineralized fissures. Those near Alta extend mostly north of east. Those in the Dutchman, Live Yankee, and Miller mines of the American Fork area extend northeasterly, and for a part of their course form one wall to the veins. The dikes, however, were introduced before the veins were formed. The fissures are distinctly later than the overthrust, but the presence of the dikes is proof that some of these fissures were formed before the cessation of igneous intrusion. The presence of veins along some of the dikes is proof that the same fissures, or fissure zones, were reopened shortly after the dike intrusion, and the presence of mineralized fissures within the main intrusive bodies is evidence that some of the fissures were not formed until the intrusive rock had become solid enough to undergo fracturing. There has been movement along at least some of these fissures, but the amount of movement is in most places not readily determined. Here and there it is known to have been slight, and nowhere has it been demonstrated to have been very great.

It is believed that the fissures were formed at the time of intrusion as an effect of the doming of the sedimentary rocks. It should be expected that the strongest fissures would lie parallel and near to the

common major axis of the intrusive bodies. This direction furthermore coincides essentially with the axis of the principal fissures of the Park City district, which are also closely associated with the Clayton Peak stock of quartz diorite. The northeasterly fissures of the Cardiff and Branborg mines and the easterly fissures of the American Fork mines are radial with respect to the granodiorite stock. The northeasterly fissures of the American Fork mines are concentric with respect to the same body. Radial and concentric fissures are the ones most likely to be formed as a result of doming, and also the contraction of the domed area during the cooling of the newly intruded igneous bodies. The observations made, however, are too few and localized to give more than a suggestion of these structural relations. Settling of the area at intervals throughout the cooling stage may account for the displacements noted along these fissures, some displacements preceding and others following the deposition of the vein minerals.

FAULTS DISTINCTLY LATER THAN IGNEOUS INTRUSION AND ORE DEPOSITION.

Faults distinctly later than igneous intrusion and ore deposition may be conveniently classified into two groups—local faults, intimately associated with ore bodies, and those of great extent, associated with the formation of the mountain range. The only proved member of the first group, so far as the writers know, is the normal fault that offsets the vein in the Pacific mine of the American Fork district. This fault trends N. 70° W. and has a horizontal displacement of 18 feet. The abrupt terminations of some of the larger ore bodies of the region, such as the Miller body, in the American Fork district, may be due to faulting, but in none of these places, so far as the writers are aware, has the existence of a fault been proved, nor is it known in places where faulting is supposed to have occurred whether the ore body terminates against the impervious wall of a premineral fault or whether it has been displaced by a postmineral fault. It was stated by the managers that one of the large ore bodies of the Columbus Consolidated (Wasatch) mine gave out against a fault, and recently it has been reported that the ore body has been located on the other side of the fault. This fault was not accessible underground at the time of visit.

Other normal faults of small displacement are present in the region, but as they are not intimately associated with mineralized fissures their age can not be closely determined. Examples of such faults may be seen on the divide north of the Toledo mine and around the head of American Fork canyon. These were evidently of later origin than the overthrust and probably later than the reverse

faults and the concentric and radial fissures that are believed to have been closely associated with the igneous activity of the region. They are possibly to be correlated with the northerly fissuring and faulting in the Park City district and may have been contemporaneous with the great Wasatch fault.

The latest large structural feature of the region is believed to be the great normal fault that extends along the front or west edge of the Wasatch Range. Its vertical displacement is doubtless to be measured in thousands of feet. This displacement probably produced an eastward tilting of the great Wasatch block, so that the eastward dip of the strata was somewhat steepened. The growth of this great fault was gradual and may well have been accompanied by the development of many minor faults in the region, but, as already shown, a definite correlation of most of these minor faults is impossible at present.

Evidence in the Park City region[1] indicates that the igneous intrusions took place in late Cretaceous or early Tertiary time, and evidence in the southern and northern parts of the Wasatch Mountains[2] indicates that the faulting along that range occurred after the depositions of Ecoene sediments and that in some of the "Basin Ranges" faulting had ceased before the deposition of Pliocene sediments. G. K. Gilbert has shown that faulting along the Wasatch Range has occurred in very recent times. The normal faults that preceded and followed ore deposition may well have been in process of formation throughout the period that followed the igneous intrusion, and even the most detailed mapping may not produce evidence on which the normal faults may be classified into distinct groups.

ALTERATION OF THE SEDIMENTARY ROCKS RESULTING FROM THE INTRUSION OF THE GRANODIORITE AND QUARTZ DIORITE.

The reconnaissance work was not extended over sufficient territory or pursued with sufficient detail to establish definitely the types of alteration that were due to regional metamorphism and those that are to be attributed to the influence of the intrusive bodies. Regional metamorphism, however, has been comparatively slight in the great limestone and overlying rocks, and the cause of changes in these rocks can be more certainly determined.

The Little Cottonwood stock of granodiorite in the area examined is in contact with the Cambrian and pre-Cambrian quartzites and schists. Both have undergone considerable regional metamorphism,

[1] Boutwell, J. M., op. cit., p. 43.

[2] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, No. 5, p. 451, 1913. (Eocene conglomerate is displaced by "Basin Range" faults.) Mansfield, G. R., unpublished map of the Montpelier quadrangle, U. S. Geol. Survey. (Pliocene lake beds lie undisturbed in the valleys between faulted "Basin Ranges.")

and they were not examined with sufficient care outside of the zone influenced by the intrusive body to determine what the changes have been within that zone. Specimens of schist collected at the contact in a gulch west of Superior Gulch are composed of quartz, orthoclase, some plagioclase, rather abundant zoisite, abundant magnetite, and small amounts of muscovite and biotite. The rocks near the contact appear to contain more magnetite and less mica than those at a greater distance. The effect of the intrusion on the Cambrian quartzite does not appear to have been great but was not closely studied. Its effect on the great limestone series along the southern boundary of the area mapped is expressed by a general bleaching and recrystallizing of the originally dark limestone into white marble and by the development of such typical contact minerals as pyroxene, tremolite, brown garnet, epidote, quartz, and pyrite—the same general effect as those that accompanied the intrusion of the quartz diorite.

The Clayton Peak mass of quartz diorite is almost wholly in contact with the limestone and its metamorphic influence has received more attention, but by no means detailed study. Alteration of the "contact" type associated with the main body of intrusive rock was noted especially in the vicinity of the Alta Consolidated and City Rock mines and associated with lesser intrusive bodies north of Lake Solitude and in the workings of the South Hecla mine. Much of the limestone near the intrusive mass has been recrystallized and bleached, but the development of abundant contact silicates has occurred only at certain points and was apparently associated with certain beds in the limestone. Some of the replaced beds could be traced for several hundred feet from the contact, but other replacement bodies were noted several hundred feet from an observed igneous contact and with no apparent direct connection with an igneous rock. The principal contact minerals noted were diopside, a light yellow and a beautiful green garnet, monticellite, muscovite, ludwigite, green phlogopite, magnetite, hematite, and iron and copper sulphides. Other contact minerals are probably present, such as vesuvianite and spinel, which have been noted farther east in the Park City area.

ORE DEPOSITS.

HISTORY AND PRODUCTION.[1]

LITTLE COTTONWOOD DISTRICT.

Ore was first discovered in the Little Cottonwood district by Gen. Conner's soldiers in 1864, and the Wasatch district was then organized, but it was soon abandoned owing to the great expense of work-

[1] The section on history and production (pp. 183–199) was written by V. C. Heikes.

ing. In 1867 most of the claims were "jumped" and a new district organized, called the Mountain Lake, which included a large area in the Wasatch Range. It was divided in 1869–70 into the Little and Big Cottonwood, American Fork, and Uinta districts. The mining claims recorded in the Little Cottonwood district covered an area about 2½ miles square. Most of the principal mines of the Little Cottonwood district are on the northern slope of the Little Cottonwood Canyon. Alta, the principal camp, is 16 miles east of Sandy, a station on the Denver & Rio Grande and San Pedro, Los Angeles & Salt Lake railroads. A railroad was completed to the district in May, 1873, but was discontinued a few years later. In 1913 the grade was repaired and rails laid as far as Wasatch for the transportation of building stone to Salt Lake City. The mine operators in the district took advantage of this renewed method of transportation, thus saving a wagon haul of 9 miles to the smelters. The most productive period was between 1871 and 1877, and at the time of Huntley's visit[1] (October, 1880) the district was very dull and but two mines—the Vallejo and the City Rock—were working regularly. This idleness of the mines was due to several causes, including legal troubles, the exhaustion of working capital of several large prospecting companies, the giving out of surface bodies, the finding of pyrite and water in the lower levels, and the low price of lead.

Very little metallurgic work was ever done in the district, as most of the ore was sold in the Salt Lake market. In 1866 the owner of the North Star mine built a Scotch hearth furnace and ran out about 3 tons of lead. In the following year he erected a reverberatory furnace and a cupel furnace. The former was a success, but the latter failed. The Jones smelter, about 4½ miles from the mouth of Little Cottonwood Canyon, was operated in 1871, and ran on custom ores for two years. In 1872 or 1873 the Davenport smelter was started at the same place. In addition to the ore from the mine it worked some custom ore, but was shut down in 1875. The Flagstaff Co. also erected three stacks in this vicinity. Several unsuccessful attempts were made to leach ores on a small scale. Concentration works were built for the Emma mine and were financially successful, though the percentage obtained was low.

The history of the Emma mine is given by Huntley,[2] who reported on it and other mines as follows:

The Emma mine is situated halfway up the southern slope of a high, steep ridge called Emma Hill. It was located in 1868 by Woodman, Chisholm, Woodhull & Reich. Little work was done until the autumn of 1869, when the ore

[1] Huntley, D. B., The mining industries of Utah: Tenth Census U. S., vol. 13, p. 422, 1880.
[2] Idem, p. 423.

body was struck. Some ore was shipped and sold prior to the sale of the mine to the Emma Mining Co., of New York, in 1870. This company worked the mine quite vigorously and shipped a large amount of ore. The following year the property was sold to the Emma Silver Mining Co. of Utah (Ltd.) for $5,000,000 cash; another authority placed the price at $3,500,000. The mine was then worked by English managers, paid $300,000 in dividends (one authority says $1,300,000) until September, 1874, when it was attached by T. W. Park and others for an indebtedness of $300,000. It was then idle until October, 1877, when the American Emma Mining Co. was incorporated and work resumed.[1] The second ore body failed in the autumn of 1873, up to which time most of the ore had been shipped to Swansea, Wales. During the years 1873, 1874, 1878, and 1879 much low-grade ore was concentrated by jigs.

When the American Emma Co. began work it first prospected the old ore bodies and then leased the Bay City tunnel, which was 1,700 feet long and 90 feet below the lowest old workings of the Emma. This tunnel had been run by a St. Louis company at a cost of $75,000 and had been abandoned in 1876. Since making the connection a small ocher-stained seam, in an incline or winze 130 feet below the tunnel level, has been followed. * * * About 3,500 gallons of water per hour is raised. During the census year about 14 men were employed. The property of this company consists of the Emma, 2,400 by 100 feet, and the Cincinnati, 1,200 by 100 feet. One hundred thousand dollars was paid for the latter, but, the claim having been jumped, the title is in dispute. * * * From Mr. Charles Smith, of Salt Lake City, whose accounts included all but the first few hundred tons sold, the writer learned that the sales of ore to June 1, 1880, amounted to 27,451 tons, for which $2,637,727.44 was received. The mine had been developed below the discovery only about 500 feet vertically and 350 feet horizontally. The openings of the old workings were estimated at something less than 4,000 feet, and those of the new workings at about 700 feet.

The Flagstaff mine is situated a quarter of a mile north of Alta, halfway up the southern slope of a high ridge which separates Big from Little Cottonwood Canyon, from 700 to 800 feet above the valley. It was located in 1879 by Groesbeck, Schneider, and others, who worked it under the name of the Salt Lake Mining Co. until February, 1872, when it was bonded to one Davis for $300,000, who sold it to English capitalists for $1,500,000. They organized the Flagstaff Silver Mining Co. of Utah (Ltd.) and worked the mine in a very expensive manner until December, 1873, when the ore bodies in sight gave out. The company was then found to be in debt to Davis for money advanced, some $300,000. Davis took the mine and worked it under agreement with the company until December 24, 1876, when he was dispossessed by the United States marshal under orders from the English directors. Heavy lawsuits with small results followed. Since 1876 the mine has been leased and subleased many times, but has been idle since the summer of 1880. At the time of examination it was owned by Seligman Bros., of New York, who took it for debt. * * * The English company erected the Flagstaff smelter (three stacks) at the mouth of Little Cottonwood Canyon and ran it until November, 1873, when they leased the Last Chance smelter near Sandy. Smelting was not as profitable as selling the ore, which, after April, 1876, was disposed of in the Salt Lake market. The divi-

[1] There has been a great amount of litigation between the English stockholders and T. W. Park and others, but these differences have recently [about 1880] been amicably adjusted.

dends paid to the English company amounted to about $350,000. The property consists of the Flagstaff, South Star and Titus, Virginia, and Nabob. The Flagstaff is 2,200 by 100 feet, but it extends across and not along the belt. In early times, before the suits, the right to "swing their patent" was insisted on, and the workings extended 1,000 feet or more on the belt. * * *

The total product was estimated by the superintendent to be as follows:

	Tons.
Prior to 1872	6,000
1872	8,000
1873	17,000
1874 to 1876	35,000
1877 and 1878	30,000
1879	4,000
	100,000

Of this, 30,000 tons probably assayed $10 gold, 60 ounces silver, and 40 per cent lead and sold for or was worth $80 per ton. The remainder probably assayed $4 gold, 30 ounces silver, and 20 per cent lead and was worth $30 per ton.

The mine is developed by a 530-foot tunnel, from which there is an incline 515 feet in length, at an angle of 49°. From this incline there are six levels, from 700 to 1,400 feet in length. The lower level is about 700 feet vertically below the discovery croppings. The total cuttings, exclusive of stopes, are variously estimated at from 9,000 to 14,000 feet. From the mouth of the tunnel the ore is sent to the foot of the hill on a tramway 2,800 feet in length. * * *

The South Star and Titus, an older location than the Flagstaff, has been constantly harassed by lawsuits. Several hundred thousand dollars' worth of ore has been extracted. It is developed by tunnel and shaft to the extent of several thousand feet. Active work ceased in 1878.

The Nabob was located in 1876. A large body of ore, lying partly in the Virginia ground, was struck in the winter of 1876–77, which yielded about $100,000. Little has been done since. The mine is a part of the mineral belt of Emma Hill. An ore body, 30 by 25 by 4 feet, was found not 50 feet from the surface. The average assay of this ore was $74.76, of which $26 was gold. The developments consist of a 115-foot incline and 300 feet of other cuttings.

The Joab Lawrence Co., the principal actively working company on Emma Hill at the time of the writer's visit, was organized in the spring of 1879. Its property consists of the Vallejo and the North Star, adjacent claims, situated between the Emma and the Flagstaff. The North Star was one of the earliest claims of the district, having been located in 1865, and has yielded largely. There are said to be large bodies of low-grade oxide of iron ore in the lower levels, but little had been done for some time excepting a small amount of "tribute" work. The Vallejo was worked in 1872, 1873, 1874, 1875, and 1877 by several companies, and much ore was extracted. It was being worked on an extensive scale at the time of the writer's visit. * * * It [the ore] was fine and contained from 20 to 45 per cent lead and from 15 to 90 ounces silver, from 20 to 35 per cent iron and from 9 to 14 per cent of moisture. It was in great demand among the smelters owing to the lack of silica and the presence of so much iron. A low grade of ore containing from 40 to 50 per cent of iron, no lead, and a few ounces of silver was also shipped. The following table

shows the price received per ton for some lots of ore in February and March, 1880:

Weight.	Assay value.		Price received per ton.
	Lead.	Silver.	
Pounds.	*Per cent.*	*Ounces.*	
111,855	5	5	$10.00
76,225	41	48	66.50
56,877	42	65	85.10
54,376	35	39	52.25
74,011	12	15	17.50
130,304	43	54	73.75
140,525	6	9	12.00

The ore was transported from the mine to the tramway of the Wasatch & Jordan Valley Railway by a wire-rope tramway.

The Toledo-Utah Silver Mining & Smelting Co. bought the Toledo mine shortly after its discovery in 1872 and worked it quite extensively until April, 1880. The property consists of the Toledo and the Fuller claims. On the latter most of the ore has been found and most of the work done. * * * The mine is operated through a shaft 455 feet deep, vertical for part of its length. The horizontal development of the vein is 350 feet, and the total cuttings are estimated at 2,000 feet. * * * The total product of the mine and its output during the census year were large. The exact figures can not be given, owing to the confidential character of the information furnished.

The Emily mine is situated in a small ravine between the Toledo and Emma Hill. It was discovered in 1870. It is owned by the Emily Mining Co., of Pittsburgh, Pa. They ceased regular work in 1874, and the mine has been leased since at one-fifth royalty. It is a bedded vein of clay slate in quartzite, dipping about 60° E. The ore is from 1 to 6 inches wide and consists of quartz containing pyrite, sphalerite, galena, and tetrahedrite. When sorted it assays from $80 to $100. Mine is opened by three tunnels on the vein. The total length of cuttings is 800 feet. The mine is very wet and has no machinery. The total yield has been $15,000 or $20,000.

City Rock and Utah group is situated at the head of Little Cottonwood Canyon and comprises the Utah, 100 by 1,000 feet; City Rock, 100 by 1,000 feet; West Wind, 100 by 495 feet; King of the West, Utah No. 2, Utah No. 3, and Freeland. The first three are on the Utah vein, and the others are on the parallel King of the West vein, 200 feet distant, and have but little development. Most of these claims were located in 1870. In 1872 much work was done. Between 1872 and 1876 the mines were involved in litigation. Twelve men were employed during the census year. * * * The mine was being thoroughly opened at intervals of 100 feet by levels and winzes through the ore bodies. Very little stoping has been done. The developments consisted of two inclines and three tunnels on the vein. The lower one, which was to be the main working tunnel, is 5 by 7 feet, well timbered, has an iron rail track, and is 600 feet long. The middle tunnel, 490 feet vertically above the lower one, is 1,300 feet long. One hundred feet below this is the water level. The upper tunnel is 600 feet long and 201 feet above the middle one. These tunnels have a grade of half an inch in 12 feet. The total cuttings amount to 4,800 feet. During the census year 385 tons of ore were sold for $25,480.67. The previous product was estimated at $50,000.

The other mines of the Little Cottonwood district are:

Mine.	Total length of openings.	Total product.	Condition at close of the census year.	Remarks.
	Feet.			
Cincinnati group	1,500	$10,000	Worked irregularly	Ore, a sulphuret containing considerable zinc.
Enterprise	500		Idle	One ore body yielded $10,000 or more.
Dexter Consolidated	300	Small.	do	
Brian lode		(a)	do	
Marion group	1,800		Worked irregularly	
Manitoba	630		Idle	Vein not well defined.
Emily	800	18,000	Worked on lease	Ore assays $80 to $100 per ton.
Caledonia	700		do	Several thousand dollars have been extracted.
Highland Chief	1,100		Idle	Ore assays 20 ounces silver and 25 per cent lead. Many hundred tons have been shipped.
Ohio River group	500	60,000	Little work done	
Savage and Montezuma group.	3,000	200,000	Idle	Ore 35 per cent lead and 35 to 150 ounces silver.
Stoker	450	Small.	do	Ore medium grade.
McKay and Revolution	1,000		Tunnel being run	A few hundred tons have been extracted.
Grizzly and Lavinia	3,000	Large.	Idle	Contains large bodies of low-grade ore.
Darlington	500	Small.	do	
Davenport	4,800	600,000	do	
Island	1,000		do	Do.
Siskiyou	500	Small.	do	
Alpha	500	37,000		Average assays: 200 ounces silver, 10 per cent lead, $10 gold.
Evergreen			Worked irregularly	
North Pole	300			Ore, galena in small seams in limestone.
Albion and Rising Sun	1,800	100,000	Idle	
Oxford and Geneva	1,910	20,000	Worked on lease	Ore assays 30 to 90 ounces silver, 40 to 60 per cent lead, $3 gold.
Louisa	600	8,000	Idle	Ore, 10 to 12 ounces ochery carbonate and 40 to 50 ounces galena.
Sedan	300	Small.		Ore, cerusite, galena, and pyrites, containing 16 to 60 ounces silver.
Fritz	460	Small.		Vein, 20 feet; soft, low-grade ocher.
Peruvian	700	Small.		A few tons shipped, assaying 40 to 60 ounces silver, 40 to 70 per cent lead, and $6 gold.
Kenosha	500	Small.		
Highland Boy	500	None.		Small stringers of carbonate ore in limestone.

[a] A few thousand dollars.

TUNNEL SITES.

The topography of this district is very favorable for the location of tunnel sites. Accordingly, in early times, work was begun upon a great many. They have cost fortunes, but have rarely been successful in finding ore; and though all are still claimed, few are worked more than is sufficient for assessment work. These tunnel sites, in a legal way, are a great drawback to the district. They were located before many of the present claims; they ran in all directions, and, in case large and rich ore bodies should be found, some of them might be used to make serious legal difficulties. The following are the principal tunnel sites in the order of their situation, beginning at the west, on the north side of Little Cottonwood, and continuing in a semicircle around the head of the canyon:

The Frederick tunnel.—This was driven to develop the Frederick and Crown Point claims. These are parallel veins, 70 feet apart, 3 and 4½ feet wide, dip-

ping 54° N. in limestone and between limestone and quartzite. The ore is a carbonate, 18 inches wide, and averages 60 ounces silver and 35 per cent lead. The claims were located in 1870 and were worked until 1873, when water and galena were encountered at a depth of 337 feet. The value of the ore sold was estimated at $35,000. The mines were leased until May, 1876, when the tunnel was begun. It is 1,300 feet long and has to be driven several hundred feet farther before cutting the veins, which are expected to be reached at 980 feet below the croppings. Its size is 6 feet 6 inches by 4 feet 4 inches. Timbering is unnecessary. * * *

The Howland tunnel.—Work was begun on this several years ago. It has been relocated several times and was, at the period under review, known as the Solitary. Its length is 600 feet. Only assessment work is being done.

The Geneva tunnel.—Abandoned. Length unknown.

The Lady Emma tunnel.—Length, 370 feet. Relocated and called the Prince of the Hills. Only assessment work is being done.

The Chicago tunnel.—Length, 600 feet. Relocated and called the Fitzgerald tunnel.

The Vallejo tunnel.—Used in the early development of the Vallejo mine.

The Utah tunnel.—Relocated as the Burgess and used to work the Vallejo mine.

The Gladiator tunnel.—Length, about 1,000 feet. Used to work the North Star mine.

The Great Salt Lake Tunnel & Mining Co.—This is better known as the Buffalo tunnel. It was located in 1871, is 600 feet in length, and is regularly worked, 275 feet having been run the preceding year. This company has located two claims, the Buffalo and another, having 9-inch veins, containing galena and pyrites. Three small bodies were found. The ore sold for about $80 per ton and yielded a few thousand dollars. The Allegan mine, operated through this tunnel, has about 550 feet of cuttings and yielded a few thousand dollars some years ago.

The Bay City tunnel.—Length, 1,700 feet. * * *

The Illinois tunnel.—Length, 800 feet. * * *

The Equitable Tunnel & Mining Co.—This company's tunnel is about 1,500 feet in length, with side drifts and winzes amounting to 900 feet, and is situated above the Bay City. Three small claims, Bolles & Collins, Equitable, and Equitable No. 2, as well as the Phoenix and the Lady Esten tunnel site, in other parts of the district, are owned by this company. * * *

The Little Cottonwood tunnel.—Relocated and called the Buckland. It is 600 feet long and was run to tap the Savage and Montezuma group.

The Reliance tunnel.—Abandoned. Little work done.

The Manhattan tunnel.—Abandoned and relocated as the McKay and Revolution. Length, 500 feet.

The Ely tunnel.—Abandoned.

The Phoenix tunnel.—Owned by the Equitable Tunnel & Mining Co. Length, 700 feet.

The Herman tunnel, known as the Tilden.—Length, 500 feet.

The Emma Hill tunnel.—Length, 900 feet.

The Victoria tunnel.—Length, 900 feet. Used to work the Victoria, Imperial, Emma May, and Alice mines. These have a large amount of cuttings, have shipped considerable ore, and are being worked upon lease.

The Christiana tunnel, known as the Oneida.—Length, 250 feet.

The Brewer & Lapham tunnel.—Length, 150 feet. Located to develop the Darlington mine.

The Lady Esten tunnel.—Length, 300 feet. Owned by the Equitable Tunnel & Mining Co.

The Iris Tunnel Co.—This was a San Francisco company which began work in the spring of 1872 and failed in the autumn of 1877 having spent about $100,000. The tunnel was taken by one of the creditors for debt. The property consists of eight locations and two tunnel sites on Emerald Hill. The upper tunnel is 1,165 feet in length and has 600 feet of drifts. Two veins, from 6 inches to 2 feet and from 2 to 4 feet wide, were cut. Some galena and pyrite ore was extracted. Water is very plentiful, and the lower tunnel, 300 feet below, was run to drain the ledges. The lower tunnel is 635 feet long and has to be run 300 feet farther before cutting the first vein. The tunnels are large and straight and are ventilated by means of a water blast driven by the waste water.

The Etna, St. Joseph, Wasatch, Silver Belt, and Rothschild tunnel sites are of varying lengths and have all been abandoned.

Besides the tunnels above mentioned, there are many others having more or less development.

In recent years (1901–1913) the most important producers in the Little Cottonwood district, named in the order of greatest output, have been the Columbus Consolidated group; the Continental-Alta, reorganized as the Unity and later as the Michigan-Utah Mining Co. (this included the early producing claims known as the Darlington, Grizzly, Regulator, and Lavinia); the City Rocks, now part of the Michigan-Utah group (this included the Utah, an early producer); and the South Hecla (includes the Alta Hecla, South Columbus, and Wedge). The Flagstaff and the Columbus Consolidated are now owned by the Wasatch Mines Co. For several years the Columbus Consolidated operated a concentration mill, but it was destroyed by fire in September, 1914.

The Little Cottonwood district has yielded a regular production of metal annually since 1867 and may be expected to continue productive for many years to come. Unfortunately, no complete records were kept of the annual production in the early period of operation, but enough data are available to make very close estimates possible. Such data are found in the statistical reports on mines and mining in the States and Territories west of the Rocky Mountains for the years 1867 to 1876. Between 1875 and 1880 statistics were not compiled by the Government, and for these years the mining journals and the Salt Lake Tribune furnish statistics. The operations and statistics of many of the most prominent producers from 1870 to 1880 were ably reviewed by D. B. Huntley in volume 13 of the Tenth Census report. During the succeeding years the reports of the Director of the Mint give fragmentary figures until the year 1901, and the statistics from that year to the end of 1913 have been compiled by the United States Geological Survey. In the tables of production (pp. 193–194) the statistics are combined with those for the Big Cottonwood district.

BIG COTTONWOOD DISTRICT.

The Big Cottonwood district, organized July 11, 1870, is in Cottonwood Canyon, in Salt Lake County, north and east of the Little Cottonwood district, its boundaries being the summits of the ridges on each side of the canyon. Most of the mines are on the southern ridge. Most of the ore, from the earliest days, has been hauled by wagon down the canyon to Sandy, at present a station of the Denver & Rio Grande and San Pedro, Los Angeles & Salt Lake railroads, or directly to the smelters and samplers in that vicinity.

The Maxfield mine, on the north side of Cottonwood Canyon, is 14 miles east of Sandy. Argenta, in the seventies the principal mining camp of the district, is but a quarter of a mile from the Maxfield mine. This property, up to the year 1880, was mostly patented and only slightly developed. During 1880, according to Huntley,[1] it produced about 90 tons of lead ore, containing 30 to 100 ounces of silver, which was sold for $4,518. The value of the product prior to 1880 was roughly estimated at $20,000. Transportation costs in 1880 to Sandy were $4 to $4.50 a ton. The shipments made in 1880 averaged 60 ounces of silver to the ton and 35 per cent of lead. The most productive period of the mine was in 1892 and 1893. No records are available of the total quantity of silver and lead produced from the mine, but it is reported[2] that $1,053,000 would cover the total yield of the property from 1875 to the end of 1906. Since 1906 lessees have produced some lead ore each year. The total dividends paid by the Maxfield Co. amounted to $118,000. The mine was pumped out early in 1915, with a view to further development.

On the south side of Cottonwood Canyon there are several side ravines or forks, including Mill, South, Honeycomb, Silver, Days, Mill D South, and Mineral. Between Honeycomb and Silver forks, 2½ miles northeast of Alta, is the Prince of Wales group, consisting of the Antelope, Prince of Wales, Wandering Boy, Highland Chief, Wellington, and Warrior claims. All were discovered about 1870. Very important lawsuits were pending between 1871 and 1875, in which the owners of the Highland Chief were defeated and a compromise was effected with the owners of the Wellington. The Prince of Wales group is credited with a production of 10,121 tons of ore[3] to the end of 1890. Since that time a very little has been produced by lessees, who in 1909, 1910, and 1911 made shipments of ore containing 0.01 ounce of gold and 90 to 144 ounces of silver to the ton, 1.25 to 3.75 per cent of copper, and 12 to 21 per cent of lead. Assays made on shipments in 1879 show the lead to have averaged between 25 and 48 per cent and the silver between 61 and 224 ounces. Mining

[1] Huntley, D. B., op. cit., p. 428.

[2] Personal statement of A. L. Thomas, jr., Salt Lake City.

[3] Compiled from reports of Director of Mint and commissioners, 1870–1890.

by lessees was discontinued because of the large amount of water present in the lower workings, to which the ore is said to extend. The total value of the ore produced from the Prince of Wales group between 1870 and 1890, including a few shipments since, is variously estimated from $1,012,000 to $2,000,000. According to Huntley,[1] about 30 men were employed in 1880, many of them working under contracts or leases. He says:

The mine is opened by several tunnels, the main one being 2,200 feet long and running on the vein entirely through the ridge, and an 1,100-foot incline, on which there are hoisting works, on the crest of the ridge. The cuttings are said to be 1,300 feet in extent.

The Richmond and Theresa claims, south of the Prince of Wales, had about 1,400 feet of openings and produced lead-silver ore valued at $150,000 to the end of 1880. The Reed and Benson claims are often mentioned in early reviews as producers of rich ore. Subsequently these and other claims in the vicinity were incorporated into the Kennebec group, whose record as a producer was not important. Huntley[2] estimates the total product to 1880 at $600,000.

The Ophir, discovered in 1870, according to Huntley, had produced about $30,000 worth of ore to 1880.

The mines of the Kessler Mining Co., later purchased by the Carbonate Co., are estimated by Huntley to have produced ore valued at about $380,000 previous to 1880.

Other mines active in the district previous to 1880 are mentioned by Huntley as follows:

Mine.	Total length of openings.	Total product.	Condition at close of the census year (1880).	Remarks.
	Feet.			
Silver Mountain Mining Co.	500	$10,000	Active	Ore assays 50 ounces silver, 35 per cent lead, and $3 gold.
Thor and Bright Point	500	2,000	do	Ore assays 60 to 100 ounces silver and 40 to 60 per cent lead.
Elgin Mining Co.	700	Small.	Prospected irregularly.	Veins small.
Puterbaugh	300	[a] 840		
Imperial Mining, Milling & Smelting Co.		Small.		A few hundred feet of cuttings. Worked irregularly for two other years.
Dolly Varden	1,400	25,000		Property in litigation.

[a] During 1880.

In recent years very few properties in the Big Cottonwood district have produced any ore. The more productive have been the Black Bess group of the Michigan-Utah Mining Co., the Maxfield, and the Cardiff. It is impossible to segregate the production of the district from that generally credited to the Little Cottonwood district; therefore, all the statistics available for the Big Cottonwood district have been combined in the table with those of the Little Cottonwood district in the table below.

[1] Huntley, D. B., op. cit., p. 428.
[2] Idem, p. 429.

Production of metals in Big and Little Cottonwood mining districts, 1901–1913, by years.

Year.	Ore mined.	Gold.		Silver.		Copper.		Lead.		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Short tons.	*Fine oz.*		*Fine oz.*		*Pounds.*		*Pounds.*		
1901	935	161.19	$3,332	37,532	$22,519	....	....	300,298	$12,913	$38,764
1902	850	146.53	3,029	34,120	18,084	58,490	$7,136	272,999	11,193	39,442
1903	1,977	85.24	1,762	69,336	37,441	102,260	14,010	552,483	23,204	76,417
1904	4,878	306.36	6,333	106,249	60,828	235,832	29,479	1,190,005	52,063	148,703
1905	26,003	949.99	19,638	371,683	224,496	811,639	126,616	1,702,258	80,006	450,756
1906	20,801	762.05	15,753	345,102	231,218	1,193,743	230,392	1,922,276	109,570	586,933
1907	19,896	976.93	20,195	399,417	263,615	1,074,238	214,848	2,337,924	123,910	622,568
1908	5,866	321.36	6,643	63,246	33,520	269,212	35,536	603,840	25,362	101,061
1909	13,208	335.72	6,940	158,867	82,611	1,842,711	239,553	332,475	14,296	343,400
1910	14,203	381.87	7,894	202,010	109,085	804,018	102,110	1,102,907	48,528	267,617
1911	6,040	139.17	2,877	158,448	83,978	407,719	50,965	1,043,608	46,963	184,783
1912	6,566	142.46	2,945	186,183	114,503	386,963	63,849	1,135,191	51,084	232,381
1913	5,167	112.08	2,317	93,821	56,668	136,901	21,219	1,091,617	48,031	128,236
	[a] 126,390	4,820.95	99,658	2,226,014	1,338,566	7,323,726	1,135,713	13,587,881	647,123	3,221,060

[a] Within the period covered by this total the Columbus Consolidated Co. operated its concentration mill from 1904 to 1912, inclusive, producing 15,172 tons of copper-lead concentrates. In 1905 the Continental Alta produced lead concentrates, and in 1910 some copper-lead concentrates were recovered from Columbus Extension ores.

Production of metals in Big and Little Cottonwood mining districts, 1867–1913, by periods.

Period.	Ore mined.	Gold.		Silver.		Copper.		Lead.		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Short tons.	*Fine ounces.*		*Fine ounces.*		*Pounds.*		*Pounds.*		
1867–1870 [a]	5,573	59.99	$1,240	703,138	$933,667			6,444,800	$387,048	$1,321,955
1871–1880 [b]	133,796	3,585.02	74,109	6,259,000	7,876,458			95,201,998	5,450,541	13,401,008
1881–1890 [c]	22,515	5,426.90	112,184	883,034	927,886			14,784,900	662,998	1,703,068
1891–1900 [d]	13,885	7,581.38	156,721	707,731	525,144			8,457,869	323,954	1,005,819
1901–1913 [e]	126,390	4,820.95	99,658	2,226,014	1,338,566	7,323,726	$1,135,713	13,587,881	647,123	3,221,060
	302,159	21,474,24	443,912	10,778,917	11,601,621	7,323,726	1,135,713	138,477,448	7,471,664	20,652,910

[a] J. R. Browne (Mineral resources of the States and Territories west of the Rocky Mountains, 1868, p. 486) refers to the operation (in 1867) of two small furnaces in Cottonwood Canyon. These furnaces were under construction in 1866, according to the Daily Union Vedette of Aug. 25, 1866, and in September they began producing lead, which evidently was lost in slag and cinders (Vedette, Oct. 26, 1867) and recovered in 1867 by a German metallurgist named Reese under the supervision of A. A. Hirst, who had reconstructed the works for treatment of North Star ores. According to R. W. Raymond (Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1870, p. 223), the first efficient smelter (a cupola), erected by Woodhull Bros., 7 miles south of Salt Lake City, began to operate in June, 1870, producing 5,000 pounds of bullion in 36 hours. Most of the ore was from the Monitor and Magnet claims (idem, p. 222). Shipments of ore from the Emma mine (located August, 1868) began in June, 1870, and up to Dec. 31, 1870, Walker Bros. had shipped 4,200 tons of ore (mostly Emma, with an average assay of 35 per cent of lead and $182 in silver to the ton). Lead bullion shipments, mostly from Cottonwood ores, were 2 tons to England and 6½ tons to San Francisco (Raymond, R. W., idem., 1872, p. 319). In the fall of 1870 mining locations in the Big Cottonwood district (the Davenport, Theresa, Wandering Boy, Maxfield, and Prince of Wales) had each yielded some ore for shipment (idem, p. 321). On the Little Cottonwood side the Emma mine had produced up to August, 1871, 10,000 to 12,000 tons of ore, which assayed 100 to 216 ounces of silver to the ton and from 30 to 66 per cent of lead, averaging 160 ounces of silver and from 45 to 50 per cent of lead. The total value of the ore, at the cash price paid for it, a large part of it at Liverpool, was about $2,000,000 (idem, p. 323). The Flagstaff mine, up to April, 1871, had yielded over 80 tons of shipping ore.

[b] Between 1871 and 1880 the largest producers were the Emma (largely depleted by 1873), Flagstaff, North Star, Vallejo, Joab Lawrence Co., City Rock, Grizzly and Lavinia, Davenport, Savage and Montezuma, Reed & Benson, and Prince of Wales. According to Huntley (op. cit., pp. 423, 424), the Emma mine had yielded to June 1, 1880, ore aggregating 27,451 tons, for which $2,637,727 was received. The rich ore bodies of the Flagstaff mine gave out in December, 1873, having produced about 31,000 tons, which probably assayed $10 in gold and 60 ounces of silver to the ton and 40 per cent of lead and which sold for $80 a ton. Between 1874 and 1879 about 69,000 tons was produced from the Flagstaff, probably assaying $4 in gold and 30 ounces of silver to the ton and 20 per cent of lead, and was sold for $30 a ton, aggregating from the beginning about $4,550,000 (idem, p. 428). The Prince of Wales and Antelope groups of claims were discovered about 1870 and had a record of producing over $1,000,000 to the end of 1882 (U. S. Mint Rept., 1884, p. 421). Subsequent records of the Prince of Wales in the Mint reports to 1890 show not over 10,121 tons of ore shipped, averaging probably 105 ounces of silver to the ton and 30 per cent of lead.

[c] Between 1881 and 1890 the Flagstaff produced in 1881, the Joab Lawrence or Vallejo and City Rocks almost continuously to 1891, and the Maxfield was the heaviest shipper in the years 1884, 1887, 1888, and 1890.

[d] In 1891 and 1892 the Maxfield and Flagstaff were the principal producers. Between 1891 and 1900 very little or no mention of these districts was made in the reports of the Director of the Mint. The figures given are differences between the known output of the other districts in Salt Lake County and the total for the county as given by the Director of the Mint in the reports for each year.

[e] Compiled from producers' reports to the United States Geological Survey.

AMERICAN FORK DISTRICT.

The American Fork district, at the head of American Fork canyon, is separated from the Little Cottonwood district by a sharp divide. It was organized July 21, 1870, and has an area of 6 square miles. The mining town, called Forest City, was 18 miles from the town of American Fork. In later years, since the decline of the Miller mine, the district has yielded only a small production.

Huntley[1] reviews the conditions as they existed in 1880 as follows:

The Miller mine, formerly the principal mine of the district, was discovered in September, 1870, and was sold the following year for $120,000 or over. The Sultana smelter (three stacks) was erected in 1871–72, and ran irregularly until the spring of 1875. In 1871–72 a narrow-gage railroad was built up the canyon to within 4 miles of the smelter, costing $240,000, if report is correct. At the same time 25 stone charcoal kilns, 15 at the smelter and 10 at the end of the railroad, were constructed. Everything was done on a grand scale. At times 200 men were employed. The ore bodies gave out, and the company shut down the mine in December, 1876, since which time it has only been worked on lease. The charcoal kilns, which were of the beehive pattern and held about 25 cords each, ran almost continuously from 1872 to 1877, making coal for the Salt Lake smelters. The track was taken up in 1878 and the iron sold. The bottoms of the old furnaces were torn up to get the large amount of lead contained in them, and the old slag dumps were profitably picked over four times to find scraps of lead, unreduced ore, and matte. * * * Various estimates are given of the total product and the average grade of the ore of the Miller mine. The range of these is between 13,000 and 15,000 tons, assaying from 40 to 54 per cent lead, from 30 to 47 ounces of silver, and from $2 to $10 gold. * * *

The Wild Dutchman mine is a quarter of a mile east of Forest City. It was discovered in 1872 and sold to the Omaha Smelting & Refining Co. of Nebraska, who worked it until September, 1876, when it was leased. * * * Five large bodies [of ore] have been found, one 20 feet from the surface, one 300 feet from the surface, and others between these. The ore is the usual ochery carbonate of lead found in a lime formation and contains small amounts of heavy spar. * * * The mine is opened by seven working tunnels from the hillsides at various levels. * * * The total product of the mine to 1880 was estimated at 7,900 tons, averaging 45 ounces of silver and 40 per cent lead.

The other mines of American Fork district are:

[1] Huntley, D. B., op. cit., pp. 444–445.

Mine.	Total length of openings.	Total product.	Condition at close of the census year.	Remarks.
	Feet.			
Pittsburg	1,185	2,000 tons.	Active	Ore assays 13 ounces silver, 44 per cent lead, and $2 gold.
Sunday	300	$17,000	5 men tunneling	
Silver Bell	[a] 120	130 tons of 100-ounce ore.	Active	
Excelsior Silver Mining Co.			do	Developments limited; ore argentiferous galena, assaying 60 ounces silver and 50 per cent lead and a trace of gold.
Utah Consolidated Mining Co.				Seven claims. Several hundred feet of developments.
Queen of the West	1,000		Idle	In 1874 $28,000 taken from one pocket.
Orphan		250 tons	Active	Ore assays 60 ounces silver and 40 per cent lead.
Live Yankee and Mary Ellen		600 tons	Idle	Ore formerly assayed 18 ounces silver, 7 per cent lead, and $4 gold.
Treasurer	475	A few tons.		Ore assayed 85 ounces silver and some lead.
Silver Dipper	600			Ore assays 10 to 20 ounces and 40 per cent lead.
Whirlwind	1,000	$3,000		
Noncompromise	400	$15,000		Ore assayed 40 ounces silver.
Hudson		None	Some prospecting done.	An extension of the Pittsburg.

[a] Incline; also some tunneling work.

After the closing of the Miller mine in 1876 assessment work was performed yearly and some ore produced and shipped. In 1904 a body of ore was found in the Miller mine, which during the next few years yielded metals to the value of several hundred thousand dollars, but since 1907 there has been a decline in the output.

The following tables show the tonnage and yield of ore produced in the district from 1901 to 1913, and by periods from 1870 to 1913:

Production of metals in American Fork district, 1901-1913, by years.

Year.	Ore.	Gold.		Silver.		Copper.		Lead.		Zinc (spelter).		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Tons.	*Fine ounces.*		*Fine ounces.*		*Pounds.*		*Pounds.*		*Pounds.*		
1901	128	35.40	$732	3,508	$2,111			76,800	$3,302			$6,145
1902	39	3.53	73	663	351			23,666	970			1,394
1903	64	21.28	440	1,872	1,011			11,214	471			1,922
1904	922	800.00	16,537	18,880	10,809			617,280	27,006			54,352
1905	2,479	1,301.00	26,894	27,740	16,755	88	$14	1,374,660	64,609			108,272
1906	2,914	2,096.82	43,345	47,611	31,899			1,959,784	111,706			186,952
1907	4,706	3,483.80	72,017	93,551	61,744	45,098	9,020	3,612,785	191,478			334,259
1908	2,356	745.52	15,411	64,840	34,365	26,073	3,442	1,386,596	58,237			111,455
1909	1,025	125.13	2,587	39,821	20,707	10,670	1,387	628,148	27,011			51,692
1910	965	183.12	3,785	34,204	18,470	12,227	1,553	519,749	22,869			46,677
1911	494	79.05	1,634	9,441	5,004	4,092	511	386,544	17,394			24,543
1912	659	121.44	2,510	11,172	6,871	3,466	572	380,630	17,128			27,081
1913	411	30.61	632	6,609	3,991	2,949	457	279,772	12,310	2,712	$152	17,542
	17,162	9,026.70	186,597	359,912	214,088	104,663	16,956	11,257,628	554,4[illegible]3	2,712	152	972,286

Production of metals in American Fork district, 1870-1913, by periods.

Period.	Gold.		Silver.		Copper.		Lead.		Zinc (spelter).		Total value.
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Fine ounces.		*Fine ounces.*		*Pounds.*		*Pounds.*		*Pounds.*		
1870-1880 [a]	3,116.10	$64,415	1,377,600	$1,683,542			14,866,000	$882,744			$2,630,701
1881-1890 [b]	526.80	10,890	32,475	34,071			693,000	30,405			75,366
1891-1900 [c]	200.00	4,134	22,000	15,876			510,000	17,655			37,665
1901-1913 [d]	9,026.70	186,597	359,912	214,088	104,663	$16,956	11,257,628	554,493	2,712	$152	972,286
	12,869.60	266,036	1,791,987	1,947,577	104,663	16,956	27,328,628	1,485,297	2,712	152	[e] 3,716,018

[a] The American Fork district was organized July 21, 1870. Work was not commenced to any extent on the mining claims until the fall of that year. The Miller mine, discovered in September, 1870, was the principal producer. In 1871-72 the Sultana smelter was built for the reduction of Miller ore and ran irregularly until the spring of 1875. The Miller ore bodies gave out and the mine was closed in December, 1876. It was in the hands of lessees at different periods to the end of 1880. D. B. Huntley (op. cit., p. 444) estimates the production of ore from the Miller mine to the end of 1880 between 13,000 and 15,000 tons, assaying from 40 to 54 per cent of lead and 30 to 47 ounces of silver and $2 to $10 in gold to the ton. In 1872 the Wild Dutchman mine was discovered and worked by the company until September, 1876, when it was leased. Its total production to 1880 was estimated at 7,900 tons of ore, averaging 45 ounces of silver to the ton and 40 per cent of lead. The Pittsburgh, Sunday, Silver Bell, Orphan, Queen of the West, Live Yankee, Whirlwind, Noncompromise, and, in the Silver Lake section, the Milkmaid and Wasatch King, were producers prior to 1880.

[b] During the period 1881-1890 development work was done, but very little ore was shipped, probably not averaging over 100 tons a year. The Director of the Mint (Rept., 1886, p. 224) shows that the aggregate shipments of the Bellerophon, Live Yankee, Milkmaid, Miller, Silver Bell, Sultana, and Wild Dutchman in 1886 amounted to 80½ tons.

[c] In 1891 the Wild Dutchman, North Star, Kalamazoo, and Live Yankee properties yielded an aggregate of 100 tons of ore, according to the Director of the Mint (Rept., 1891, p. 224). Estimates were made for the remaining years of this decade, and it is presumed that the average ore yield was not greater than in 1891.

[d] For the period 1902 to 1913, inclusive, the figures of production were collected by the Survey; those for the year 1901 are estimated from the best records available.

[e] The total ore mined between 1870 and 1880 is estimated at 39,950 tons; 1881-1890, 990 tons; 1891-1900, 1,000 tons; and 1901 to 1913, 17,162 tons, making the total output of ore 59,102 tons. This figure, used in seeking the average of the ore produced, gave $4.50 in gold and 30.32 ounces of silver to the ton and 23.12 per cent of lead, and, in value, including small quantities of copper and zinc, $62.87 to the ton.

DIVIDENDS.

Dividends aggregating several million dollars are reported to have been paid to stockholders by mining companies operating in the Little Cottonwood and Big Cottonwood districts. Some of the published statements follow, but many of the facts are discredited by old residents, who say that the managements of early mine operations were very expensive. Raymond[1] reviews a statement in which dividends are mentioned, furnished by N. M. Maxwell, superintendent of the Flagstaff mine, as follows:

The product of the Flagstaff furnaces during 1872 was 3,000 tons of metal, containing—

Silver	$390,000	; average per ton, $130
Gold	120,000	; average per ton, 40
Lead	240,000	; average per ton, 80
Total	750,000	

The capital of the company is £300,000, on which 30 per cent in dividends have been paid during the last three months and 24 per cent during those preceding, the total amount of dividends paid being £76,000.

In a later report[2] it is stated:

This splendid mine has produced during 1873, according to the directors' report, 15,000 tons of ore of an average value of $54 per ton in the ore market. The same report says the expenses for mining ought to have been $5, hauling $8, establishment charges $4, total $17, leaving $37 profit per ton. Yet there was not only no profit made, but in the fall the company was very heavily in debt and the value of shares depreciated rapidly in London.

According to Huntley,[3] who reviews conditions in the district up to October, 1880, the Emma mine, worked by English managers, paid $300,000 in dividends (one authority says $1,300,000) until September, 1874, when it was attached for an indebtedness of $300,000. It was then idle until October, 1877. The Flagstaff mine, when owned by the English company, paid dividends that amounted to about $350,000.

From all available data, the dividends paid by the mining companies in the Little and Big Cottonwood districts to the end of 1913 are as follows: Emma, $300,000; Flagstaff, $350,000; Columbus Consolidated, $212,623; Vallejo and Titus (Joab Lawrence), $180,000; Maxfield, $117,000. If $700,000 is estimated to cover the dividends realized from other properties, including the Prince of Wales, it gives a total dividend record of over $1,850,000.

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1872, p. 247, 1873.

[2] Idem for 1873, p. 260, 1874.

[3] Huntley, D. B., op. cit., p. 428.

DEVELOPMENT.

As in most other mining districts, the earliest development work on the ore bodies consisted in following them down with shafts or inclines. In this region, however, large flows of water were frequently encountered at relatively shallow depth. The heavy cost of pumping and the strong relief of the region early led to the driving of tunnels for the double purpose of draining and developing the deposits. These tunnels have been carried to increasing depths, and in recent years there has been a general tendency toward the consolidation of properties into large groups and the development of these groups by deep drainage tunnels. Such tunnels have been and are being driven from both sides of the ridge between Little Cottonwood and Cottonwood canyons.

The strong relief of the region makes it especially adapted to exploration by tunnel, and there can be no question that this is the most practical method of development. The great abundance of "fine tunnel sites" has apparently been a temptation that was hard to resist, as is shown by the scores of such works that have been started. That more than a "fine site" is necessary to the financial success of such a project, however, is indicated by the large percentage of failures that have resulted.

CLASSIFICATION OF THE ORE DEPOSITS.

GENERAL TYPES.

All the deposits of commercial importance that have been developed to the present time occur in the sedimentary rocks. Some small veins in the intrusive rocks have been prospected to a slight extent, but so far as known they have yielded no metal.[1] The deposits in the sedimentary rocks can be referred to three general types, but the separation of these types in the mines is not always readily accomplished, as they show transitions from one to another. The three main types recognized are contact deposits, fissure deposits, and bedded deposits.

At the time of visit some of the mines that have made the district famous were idle, and only meager notes concerning the occurrence of the ores in them were obtained, but the data from the active mines give a good idea of the character and relations of the different types of deposits. Data on several of the old mines have been taken from reports made by engineers at the time the mines were active.

CONTACT DEPOSITS.

Under contact deposits are included replacement deposits in limestone closely associated with intrusive rocks and containing the min-

[1] Since this was written it has been reported that several tons of molybdenum ore has been produced by the Alta-Gladstone Co. from a quartz-pyrite-molybdenite vein in the granodiorite of the Little Cottonwood stock about 2 miles west of Alta.

erals commonly known as "contact minerals," such as magnetite, garnet, and diopside. Deposits of this character are present along the north border of the Clayton Peak stock, where it is in contact with the limestone, and are also associated with smaller bodies of intrusive rock in the limestone. Certain strata in the limestone have been most susceptible to the action of the mineralizing solutions and have in some localities been partly replaced for several hundred feet from the contact.

At several places in the limestone north of the Clayton Peak stock, several hundred feet from any exposure of igneous rock, were noted deposits that are mineralogically similar to the contact deposits and are classed with them. It is possible that they are not far distant from intrusive rock which is not exposed at the surface. Deposits of this character occur along the southern border of the Clayton Peak stock and are associated with dikes in the sediments between the Clayton Peak and Little Cottonwood stocks.

Mineralogically the deposits contain, in addition to unreplaced carbonate, diopside, garnet, monticellite, muscovite, phlogopite, magnetite, hematite, and iron and copper sulphides. Two species of garnet were noted—a light-yellow variety, probably an iron-lime garnet, and a beautiful green variety, probably containing chromium. The latter was noted especially northwest of Lake Solitude. Ludwigite occurs in contact-altered limestone northeast of the City Rocks mine.

At several localities along the north border of the Clayton Peak stock the deposits contain abundant magnetite and specularite, and have a high content of iron. The copper content varies considerably. Bodies of the material are said to average above 2 per cent of copper and selected portions to average above 5 per cent. The deposits all contain small amounts of gold and silver. Owing to the high cost of transportation in the district it has not been possible to market this material at a profit, and consequently the deposits of this type have been but little developed, and have yielded little metal. In other localities in the State, where transportation is cheaper, it has been found possible to work deposits of this character, the high content of iron serving to pay part of the expense of mining and transportation.

FISSURE DEPOSITS.

GENERAL CHARACTER.

Under fissure deposits are included those in which the minerals occur mainly as a filling of fissures. In nearly all of them there is some replacement of the wall rock, and this replacement may become so extensive at certain points that the deposit approaches the

bedded type. On the other hand, contact minerals may be present in the replaced wall rocks, and such deposits approach the contact type. The fissure deposits are present at different stratigraphic horizons in the district, but where the adjacent rock is especially susceptible to replacement, either on account of chemical composition or of physical character, they give place to bedded deposits. The fissure deposits are mostly in northeasterly and east-northeasterly fissures, which usually have steep northwesterly or northerly dips, but a few have been noted in fissures trending nearly due north. They occur in rocks of very different character and composition, including the Cambrian quartzites and shales, in which the Toledo, Branborg, Cardiff (upper tunnel), Pacific, and one of the Live Yankee veins occur; the Carboniferous limestone, which is the predominant wall rock of the City Rocks vein; and even the Thaynes formation (Triassic), in which the veinlike body of the Barry-Coxe mine is located. The Dutchman, Bay State, and two of the Live Yankee veins are in early Paleozoic, probably Cambrian limestone.

VEINS IN BIG AND LITTLE COTTONWOOD DISTRICTS.

The Toledo vein was not being worked at the time of the writer's visit, though an effort was being made by the Columbus Extension Co. to locate the vein below the old workings. The following description of the vein is given by Huntley:[1]

> The ore occurs in a fissure vein, from 1 to 3 feet wide, cutting diagonally across a quartzite formation, dipping NNW. 80°, and is found in several chimneys 50 feet long on the strike and about 50 feet apart. They dip with the strike toward the east. The ore is a hard, porous brown siliceous oxide of iron of very high grade. It was said to have averaged from 80 to 109 ounces to the ton. Water was found 200 feet from the surface, but the character of the ore did not change. Where the vein passed from the quartzite into a belt of schist there was much pyrite. The mine is operated through a shaft 455 feet deep, vertical for part of its length. The horizontal development of the vein is 350 feet, and the total cuttings are estimated at 2,000 feet.

The City Rocks fissure (now Michigan-Utah mine), as developed near the surface, is thus described by Huntley:[1]

> The Utah is a fissure vein, from 1 foot to 20 feet wide, dipping 70° or more NW. through strata of blue and white siliceous limestone or dolomite, which dip about 30° NE. It had outcrops in places and is known to extend 4,000 feet in length and 700 feet in depth. The gangue of the vein is oxide of iron and a sand, apparently the result of the decomposition of the siliceous country rock. The ore is from 1 foot to 10 feet (averaging from 2 to 3 feet) wide, immediately in contact with the walls, but not confined to either. Three chimneys have been found 200 feet long and about 300 feet apart. One came to the surface, and the others to within 100 feet of it. They dip with the strike about 65° NE. The

[1] Huntley, D. B., op. cit., p. 425.

positions of these chimneys appear to be determined by the strata of white limestone. The ore makes where the vein crosses the white limestone but pinches where the harder blue limestone is encountered. It is a soft red, sometimes rather sandy oxide of iron containing carbonate of lead and galena and in places stains of malachite. The first class assays 30 per cent lead, 30 ounces and upward of silver, and a trace of gold. There is also much low-grade jigging ore in the mine. On the south side a dike of porphyry appears, running nearly parallel with the vein. Near the porphyry the ore has not been so rich.

The vein has been prospected at greater depth by the Lake Solitude tunnel, which opens it 300 feet below the City Rocks tunnel. In 1912 the vein had been developed for several hundred feet by this tunnel and a winze had been sunk 200 feet below the tunnel level to the ninth and tenth levels. A raise connects this tunnel with the City Rocks tunnel, and levels have been opened between the two. In the lower levels the vein ranges from a few inches to 3 or 4 feet in width, and where the fissure crosses certain of the limestone bedding planes replacement has extended several feet from the fissure.

The ore is oxidized to the Lake Solitude tunnel level and is said to be oxidized to the tenth level, 200 feet below the tunnel. The ore contains abundant limonite and in places rather abundant manganese oxide and notable amounts of wulfenite.[1]

The commercially important metals are lead, silver, and copper, with small amounts of gold.

Raymond[2] describes the mineralization in the Savage and Montezuma claims as follows:

Savage: This claim comprises 1,400 feet and is located high up on the hillside, about 1,500 feet above the Emma and a few hundred feet east of the Flagstaff. It is opened to a depth of over 230 feet by a single inclined prospecting shaft following the vein and without any side drifts. The ore shows near the entrance of the incline as a rusty, gossan-like mass or vein, cutting the beds of limestone vertically. A few feet below the surface, within the incline, the thickness of the vein overhead is about 3 feet. It pinches up at a point lower down and toward the bottom of the incline opens out again to a vein from 2 to 3 feet wide of rich ore, yellowish and rusty in color and in places streaked with green stains of copper. Quartz vein stone is found at the bottom of the mine, and it is hoped that this will prove to be a continuous, regular vein formation. The ore is soft and earthy, much like that from the Emma and other claims. It is rich in silver and lead. The mineral wulfenite is found disseminated in small, thin crystals throughout the vein.

The Montezuma is about 90 feet west of the dump of the Savage. The vein is vertical, or nearly so, like the Savage, and extends apparently from 3° to 5° west of north (magnetic). The croppings are rusty and rather hard, but below the ore is softer and richer in silver and lead. The country rock is a hard black limestone. This vein, like the Savage, is opened by an incline to a depth of 240 feet. This incline follows the ore, and its direction is about

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[1] Hess, F. L., Wulfenite at Alta, Utah: U. S. Geol. Survey Bull. 340, p. 238, 1908.

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 324, 1872.

N. 40° W. The vein may be said to average, where opened, 2½ feet in thickness. Some 200 tons of ore had been shipped up to July and about the same quantity remained upon the dump.

The deposits in the Columbus Consolidated mines (part of the Wasatch group) are in part fissure veins, though the larger deposits may better be classed as bedded deposits.

Huntley[1] describes the mines on Honeycomb Fork as follows:

The Butte mine, at the head of Honeycomb Fork, 2½ miles northeast of Alta, was discovered in 1869 and has been worked irregularly since. It is said to be a fissure vein in limestone, from 6 inches to 4 feet wide, dipping 55° N., and is supposed to be an extension of the Utah and City Rock of Little Cottonwood district. It outcropped for several hundred feet on the hillside in the form of a soft ocher-stained limestone. Ore occurs on the footwall in 8 or 10 lenticular bodies, from 1 inch to 3 feet wide, at considerable distance below the surface. It is a high-grade ocher and carbonate. Sometimes much black oxide of manganese is found. The mine is dry (excepting surface water) and is worked through a 200-foot tunnel. The total cuttings, including two old inclines, are 2,300 feet Nine men were employed during the census year. The total product to June 1, 1880, was estimated at $27,000.

The Oregon is an extension of the Butte. The property [is held by a Canadian corporation and] also includes four patented prospects on which very little work has been done—the Columbus, the Taylor, the Abbey, and the Black Bess. It is a fissure vein, from 1 to 15 feet (average, 3 feet) wide, dipping 60° NNE. in limestone. Only one body of ore has been found. This came to the surface and was 120 feet long, from 3 inches to 3 feet wide, and extended to a depth of 300 feet. It assayed about 50 ounces silver and 30 per cent lead. The mine contains 1,600 feet of cuttings and has been opened 350 feet on the dip and 480 feet horizontally (by means of an 8-horsepower vertical engine). Water was found at 100 feet, but no change occurred in the oxidized character of the ore. During the census year eight men were employed, and a small amount of ore was extracted. It was idle at the time of the writer's visit, owing to the loss of the lawsuit between it and the Butte. The total product to 1880 was estimated at $10,000.

The main output of the South Hecla mine has been derived from fissure deposits, though contact deposits associated with dikes are also present. The principal metals obtained in the lower workings have been copper and lead, though it is said that near the surface ores with a high lead content were mined.

Fissure deposits are said to be present in the sedimentary rocks between the Little Cottonwood and Clayton Peak stocks in the Albion and other mines, but were not examined.

The vein of the Cardiff mine, exposed in the upper tunnel, follows a fissure that strikes N. 35° E. and dips 65° NW. The wall rock is the "upper quartzite." The ore exposed in 1912 consisted of pyrite and tetrahedrite and a minor amount of galena in a quartz gangue. No zinc blende was noted. A qualitative test proved the presence of a little zinc in the tetrahedrite. No inclusions of zinc blende were

[1] Huntley, D. B., op. cit., p. 428.

detected by microscopic study of the polished mineral, but small amounts of a secondary mineral resembling covellite were noted surrounding pyrite grains in the tetrahedrite and filling minute fractures. Tetrahedrite containing a notable amount of zinc has been reported from the Park City district.[1] The ore minerals formed apparently pure bands or lenses 1 to 3 or 4 feet thick. The greatest thickness ever found was said to be 6 feet. The lenses were separated by bands of white quartz and unreplaced quartzite. The ore then mined was said to contain about 12 per cent of copper, a good proportion of silver, and \$1 to \$2 in gold to the ton. The proportion of galena was said to increase above the upper tunnel, and, locally at least, to mark the upward termination of pay ore. The ore was practically free from oxidation at and below the level of the upper tunnel. At higher levels, in a vein on which the old Cardiff shaft was sunk, lead carbonate ore was found down to a depth of 150 feet below the shaft collar. The large ore body which was found since the writers' visit and which has attracted much attention, belongs to the bedded type of deposits and will be mentioned later.

The Branborg property contains three fissures—the Garfield, Silver King, and Gustavus Adolphus—all striking N. 35°–40° E. and dipping about 60° NW. Another fissure, probably a branch of the Garfield, strikes N. 10° E. and dips about 60° W. The Garfield fissure and its branch carry ore containing pyrite, blende, and galena in a quartz gangue. They have been cut by a long adit, and the Garfield fissure has been followed by drifts to the southwest and northeast. Northeastward it pinches at the quartzite and shale contact. No prospecting for a continuation of the fissure in the limestone above the shale has been undertaken. Shallow pits in the limestone, however, have struck small quantities of lead carbonate, with a high silver content, which may be connected with northeasterly fissures.

The Silver King fissure had not been reached by the tunnel in 1912. It has been traced a long distance on the surface, from the vicinity of the tunnel southwestward across the divide into Little Cottonwood Canyon, and is in line with one of the fissures that extend downward into the granodiorite. Its mineralization is of the same type as that of the Garfield fissure.

The Gustavus Adolphus fissure also has the same type of mineralization, but its ore, so far as mined, contains less zinc and gives higher assay values than that from the Garfield fissure. The mixed sulphide ore from the fissures as a whole will probably require concentration and the separation of blende from galena to yield the best results. It appears well suited for concentration. Small amounts of oxidized ore mined from shallow workings are said to have yielded as

[1] Boutwell, J. M., op. cit., p. 109.

high as 1,000 ounces of silver to the ton, but the oxidized ores are very superficial and constitute almost negligible fractions of the entire veins.

The ore deposits seen in the Barry-Coxe mine, on the southwest slope of Scott Hill, represent a transition in character between the contact and fissure types of deposits, also between the fissure and bedded replacement types. The ore, so far as developed by shallow workings in 1912, occurs as pockets in partly metamorphosed limestone along fissures trending N. 13° W., north and east. The pay ore is found between layers of lean silicate rock and replaces the walls for a few feet from the fissure. The most pronounced replacement exposed at the time of examinaton extended 10 feet from the N. 13° W. fissure. The ore seen was a mixture of pyrite, blende, and galena in a gangue consisting essentially of garnet, diopside, sericite, and quartz. One of the easterly fissures, along a fault plane against which the ore along a northerly fissure stopped, contained green copper stains. The garnet and diopside were formed before the ore and other gangue minerals, but there was no evidence to determine whether the country rock was first partly replaced by contact-metamorphic minerals and at a distinctly later period replaced further by the ore, or whether all the minerals were deposited in definite sequence during one period. Absence of fracturing in the metamorphic minerals favors the latter view.

VEINS IN THE AMERICAN FORK DISTRICT.

The Silver Dipper vein follows a fissure that strikes N. 65° E. and dips 60°–65° NW., in Cambrian quartzite. The vein, which was worked in the seventies, is said to have consisted of pyrite and quartz with some good shoots of galena.

The Waterfall vein lies along a fault trending nearly due north between shale and quartzite. It is marked by pinches and swells, and the swells are about 4 feet thick. The ore minerals are galena, pyrite, tetrahedrite, and a little zinc blende in a gangue of quartz. It has been opened by two tunnels that extend northward and southward from the creek bed where it crosses the vein. The south tunnel in 1912 was 300 feet long, and the north tunnel about 50 feet.

Three veins have been worked or prospected on the Live Yankee property, near the head of Mary Ellen Gulch, but only one was accessible in 1912. This vein lies between a footwall of quartzite and a hanging wall of pyritized porphyry and has a N. 85° W. trend. Its ore minerals are pyrite, chalcopyrite, zinc blende, and galena, and its gangue minerals quartz and barite. One of the other veins lies along an east-west fault zone and is said to have contained the "big stope," mined in early days. The ore of the "big stope" is said to have lain

between walls of shale at the base of the limestone. Its ore minerals, to judge from specimens on the dump, were chiefly pyrite and chalcopyrite in a gangue of quartz and barite. The gold content is said to have been unusually high, ranging from $20 to $80 or more to the ton. The third vein strikes N. 40° E. in Cambrian limestone, but is said to pinch on reaching and following a porphyry dike. Specimens of its ore consist of pyrite, a little chalcopyrite, zinc blende, galena, and jamesonite in a gangue of quartz, barite, and a little ferruginous dolomite. A fourth vein, too small at its outcrop to be of much promise, strikes N. 45° E. in Cambrian limestone and consists mostly of galena in a gangue of dolomite spar. This group of veins differs from those already described in the prominence of chalcopyrite and in a corresponding high gold content. Their mineral and chemical composition, however, show them to be closely related to the other ore bodies of the region, and there is every reason to believe that they were formed at the same time.

Another source of ore on the Live Yankee property has been the glacial drift in the gulch, from which bowlders of galena ore have been washed. It is said that in some of the bowlders quartzite was attached to the ore, and this may indicate a westward continuation of the N. 85° W. vein, or possibly another vein concealed a short distance up the gulch.

A strong vein is being worked in the Pacific (Blue Rock) mine, just south of the southward bend in the American Fork canyon. The vein strikes N. 45° E. in Cambrian quartzite and at one place has a horizontal offset of 18 feet along a N. 70° W. fault. It is 4 to 8 feet in width and has been followed horizontally for about 450 feet, being worked through the lower tunnel of the mine. Below the tunnel its dip is 60° NW. Above the tunnel the dip flattens and the vein narrows upward until it coincides with a bedding plane at or near the shale contact. In the southern part of the mine the ore is continuous from the shale contact, 130 feet up the dip from the tunnel, to and beyond the lowest workings, 70 feet down the dip from the tunnel. The pay ore pinches northward as well as upward. The ore consists of galena and pyrite in a gangue of quartz and barite. The galena diminishes upward, and near the shale contact granular pyrite is the only ore mineral. The barite tends to be localized in lenticular shoots. The ore is in part milling ore and in part of shipping grade. The other workings of the Pacific mine have found showings of ore but were inaccessible in 1912.

The main vein of the Utah Centennial property, southeast of Pittsburg Lake, trends about east and shows some lead ore at the outcrop. In 1912 two tunnels were being driven to reach this vein. The eastern tunnel starts in quartzite at the upper road in a north-northeast direction and follows a narrow vein of white quartz with

some pyrite and a few small pockets of galena. The tunnel had penetrated the shale, in which the quartz of the vein has largely disappeared and dolomite and barite have become conspicuous.

Huntley[1] describes the Wild Dutchman mine as follows:

> The Wild Dutchman mine is a quarter of a mile east of Forest City. It was discovered in 1872 and sold to the Omaha Smelting & Refining Co. of Nebraska, who worked it until September, 1876, when it was leased. * * * The ore-bearing formation is a bedded vein, from 3 to 40 feet (average, 20 feet) wide, in dolomite, dipping 40° SE. This has been worked 300 feet in length and 450 feet in depth. The gangue in general consists of from 2 to 3 feet of shale upon the footwall and a soft clay containing fragments of silica, and strongly stained by oxide of iron, locally known as "lime porphyry." The ore occurs in scattered egg-shaped bunches of from a few pounds to 600 tons. Five large bodies have been found, one 20 feet from the surface, one 300 feet from the surface, and the others between these. The ore is the usual ochery carbonate of lead found in a lime formation and contains small amounts of heavy spar. At the water line, in the 450-foot tunnel level, a large body of base ore was found. This consisted of iron and copper pyrites, galena, and a very large percentage of zinc blende. A porphyry dike is said to cut through the footwall into the vein near the large bodies of ore. The mine is opened by seven working tunnels from the hillsides at various levels. The total cuttings are 3,500 feet. The lessees obtained 2,880 tons by work similar to that which was being carried on at the Miller. The total product of the mine is estimated at 7,900 tons, averaging 45 ounces silver and 40 per cent lead.

The principal vein of the Dutchman mine, seen in 1912, is in Cambrian limestone. It strikes N. 40° E. and dips vertically or steeply southeastward. Its width ranges from a mere streak up to 6 or 8 feet. Its greatest width is attained in a dark-blue limestone which overlies the lowest argillaceous limestone member of the Cambrian limestone. The vein, for most of its course, lies along the contact of a narrow porphyry dike. It ends abruptly on the northeast against a dense, blocky argillaceous limestone, which probably marks a northwesterly fault, but could not be studied closely.

A minor vein parallels the main vein. Both have been followed up to the cemented talus which caps the bedrock, and several masses of ore are said to have been found in the talus. The ore mined from both veins is mostly a sandy mixed lead and zinc carbonate. That mined by lessees in recent years is said to average about 30 per cent of lead, 9 to 17 per cent of zinc, and 50 ounces of silver to the ton. Remnants of primary ore are composed of galena and blende in a barite and carbonate gangue. Quartz is inconspicuous.

The best showings of ore recently reported in the Bay State mine, about midway between the Dutchman and Pacific mines, but on the east side of the canyon, had not been found in 1912. In that year a few small prospect tunnels showed small amounts of galena and barite impregnating a rather light gray limestone, and one showed an

[1] Huntley, D. B., op. cit., pp. 444–445.

interesting occurrence of stibnite. The stibnite, accompanied by barite and a little dolomite, forms small seams or stringers cutting both the limestone and a porphyry dike. Both the limestone and the dike are altered and have a sericitized appearance. The stibnite is partly altered to kermesite, the oxysulphide of antimony ($2Sb_2S_3.Sb_2O_3$), which occurs in tufts of minute red prismatic crystals and probably accounts for all the red staining along the stibnite seams.

BEDDED DEPOSITS.

LITTLE COTTONWOOD DISTRICT.

The bedded deposits have been the most productive of all the types in the Little Cottonwood district, and most of the "bonanza" deposits that made the district famous in the early days were of this type. Typically these deposits occur as replacements of certain beds of the sedimentary rocks adjacent to crosscutting fissures. The deposits are thus more or less tabular in form, are as a whole parallel with the bedding of the sedimentary rocks, and pitch with the intersection of the replaced bedding and the fissures commonly to the northeast. Where the replacement has extended but a short distance from the fissures the deposits have more nearly the form of "chimneys" than of tabular deposits. In some places similar deposits have formed adjacent to faults whose dip and strike do not differ greatly from those of the sedimentary rocks. Such deposits occur notably next to the overthrust fault in the western part of the district. Like the true bedded deposits, they are associated with the northeasterly fissures and have the same general form. The location of the deposits, however, is probably due in part at least to the character of the rocks that has resulted from the movement along the overthrust fault plane.

Most of the deposits are oxidized to the depth to which they have been mined, and it is not possible to determine the original replacement minerals except by scattered remnants of unaltered material. Some deposits that consist largely of sulphide have been developed, notably in the Columbus Consolidated mine. The original minerals recognized are pyrite, galena, sphalerite, and tetrahedrite in a gangue of quartz and unreplaced carbonate. Sericitic muscovite also is a common gangue mineral in the bedded as well as in the fissure deposits and is prominent both in limestone and shaly beds and in "porphyry."

From a bed in the shale series near the Columbus Consolidated mine, specimens were collected on the surface that showed green amphibole, epidote, and quartz, together with pyrite apparently replacing a dolomitic member in the shale series, but similar replacement by

the silicates was not noted underground. A specimen of tetrahedrite from the Columbus Consolidated mine was examined by R. C. Wells in the chemical laboratory of the Geological Survey and found to contain 6.24 per cent of lead, together with arsenic, as well as antimony. In the material examined no lead mineral other than the tetrahedrite was recognized, and it is believed that the lead is contained in that mineral. Whether or not the tetrahedrite of the district carries lead generally or only at certain localities has not been determined. Specimens of supposed tetrahedrite from the neighboring Park City district have been shown by F. R. Van Horn[1] to contain notable amounts of lead. It has already been noted that tetrahedrite from the Cardiff mine and from the Park City district contains zinc in notable amounts. Probably other minerals are present in the primary ores, but they were not recognized in the small number of specimens collected.

As already noted, most of the deposits have been oxidized to the depth to which they have been developed. In numerous places oxidation has extended far below the level of ground water, though it has not been demonstrated to have gone below the zone of surface drainage, as the deep canyons permit circulation to great depth in many of the veins that crop out at the higher elevations. The typical oxidized ore consists of hydrous iron oxides, with the carbonate and sulphate of lead, cerusite and anglesite, and the carbonates of copper in varying amounts, and usually contains manganese oxide.

At the time of visit oxidized ore that was being mined from the "white limestone" in the Alta Consolidated mine contained a large percentage of an undetermined ferric sulphate of lead and copper. This is a yellow earthy mineral that can usually be crushed in the fingers, though some of it forms rather hard lumps. Such lumps may have a core of galena. The mineral has not been quantitatively analyzed, but in appearance and constituents it resembles beaverite and may prove to be that mineral. One of the massive pieces of this ore was sectioned and found to have a core of galena. Surrounding the galena and extending inward along cleavage planes is a narrow zone of anglesite which gives place outward to the yellow mineral with specks of green, possibly malachite. It is evident that in this specimen the mineral has not resulted from the oxidation of a mixture of iron, lead, and copper sulphides, but that the galena has first altered to sulphate and this has subsequently combined with iron and possibly copper that has been brought to it in solution. To what extent minerals of this character were present in the large oxidized bodies of this district is not known, but it does not seem probable that they were confined to this one deposit.

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[1] Geol. Soc. America Bull., vol. 25, p. 47, 1914.

Wulfenite, the molybdate of lead, is rather abundant in the City Rocks vein and in some of the ores from the Alta Consolidated mine and is reported from other mines. It is also reported that the ores contain vanadium,[1] but no vanadium-bearing mineral was recognized. Carbonate and silicate of zinc have been recognized in the oxidized ores of the district, but nowhere in abundance. Sphalerite is rather plentiful in some of the sulphide ores, and it is to be expected that the oxidized ores of zinc will be found, but whether they are anywhere present in commercial quantities is as yet unknown.

The ore body of the Emma mine was one of the earliest discoveries, and the mine has been one of the largest producers in the district. It was located in 1868. From 1870 to 1875 it was a large producer of lead and silver, and until the early eighties it continued to produce intermittently, but for many years little work has been done on the property. The mine is in the "great limestone" series and the deposits are supposed to be in the same strata as the Flagstaff and other important deposits of the district. This limestone is cut by a strong easterly fissure and the ores are said to occur as bedded deposits adjacent to this fissure. No examination of the underground workings was made, but the following description of the ore bodies by Huntley[2] is believed to be essentially correct:

The ore-bearing formation is a belt of siliceous limestone, between a limestone hanging and a dolomite foot wall, the belt being about 200 feet wide, dipping 45° NE., parallel to the stratification of the country rock. The ore did not come to the surface, but was found by following a small seam of ocher 50 feet in a tunnel. Two large bodies were found somewhat nearer to the hanging than to the foot wall, following the general dip and strike of the belt. One began near the surface and was 100 feet deep, 300 feet long, and from 1 to 30 feet wide; and the other, a few feet below the first, was 200 feet long, 150 feet deep, and from 1 to 20 feet wide. The ore was a soft brownish-red ocher, containing cerusite, anglesite, galena, and some manganese oxide.

In 1872 Raymond[3] described the Emma mine as follows:

The Emma mine is one of the most remarkable deposits of argentiferous ore ever opened. Without any well-marked outcroppings, there was nothing upon the surface to indicate the presence of such a mass of ore except a slight discoloration of the limestone and a few ferruginous streaks visible in the face of a cut made for starting the shaft. Some of the earliest locators in the canyon assert, however, that in the little ravines below this shaft large masses of galena, some weighing over 100 pounds, were found upon the surface and in the soil. After the discovery of the deposit by means of the shaft a tunnel was run in so as to intersect it in depth. This tunnel extends in a northwesterly direction and is 365 feet long. It intersects the ore mass where it was about 60 feet long and 40 feet wide, measured horizontally. From this level, called the

[1] Hess, F. L., Wulfenite at Alta, Utah: U. S. Geol. Survey Bull. 340, p. 240, 1908.

[2] Huntley, D. B., op. cit., p. 423.

[3] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 321, 1872.

first floor, ore has been mined above and below until an excavation or chamber has been formed, varying from 20 to 50 feet in width and from 50 to 70 in length and 77 in height above the tunnel level and 50 in depth below.

In August last a portion of the ore below the tunnel level was still standing, but the mine had produced from 10,000 to 12,000 tons of ore, assaying from 100 to 216 ounces of silver per ton of 2,000 pounds and from 30 to 66 per cent of lead, averaging about 160 ounces of silver and from 45 to 50 per cent of lead. The total value of this ore, at the cash price paid for a large part of it in Liverpool, £36, or $175 in round numbers, was about $2,000,000.

This ore was extracted at comparatively little cost. Most of it was stoped from below upward and was delivered by chutes into the cars upon the tramway laid in the tunnel. In general the ore was soft and easily excavated by picks and shovels, without the aid of gunpowder. It consisted chiefly of ferruginous and earthy-looking mixtures of carbonate and oxide of lead, oxide of iron, and of antimony, mixed with nodules of galena. It appears to have resulted from the decomposition of argentiferous galena and other sulphureted and antimonial minerals containing silver. The ore may be said to be without gangue and does not require hand sorting or separating by mechanical means from worthless vein stone. This ore was shoveled up and put into sacks for shipment without any other delay or expense. The larger part was shipped overland by railroad to New York, and thence by steamer to Liverpool.

The walls of the excavation are very irregular but consist of a hard, white, dolomitic limestone. The ore mass appears to conform to the stratification and to have a general northwesterly direction, dipping to the northeast. The extent of the ore mass in the direction of its length had not been fully ascertained at some of the levels when I visited the mine in July, though in most of the floors it had all been taken out, and the form of the excavation may be taken as marking in a general way the limits of the main body. A peculiar brecciated mass of dolomitic limestone accompanies the ore and may be regarded as vein matter, for nodules of galena are found isolated in its midst, as well as small patches of soft earthy ore disconnected with the main body. The limits of this ore-bearing breccia are not yet ascertained, and prospecting drifts to the northwest along its course may reach other bodies of rich ore.

Raymond[1] quotes from a description of the ores by Silliman, as follows:

Prof. B. Silliman, of New Haven, has made some interesting investigations to determine the composition of the ores occurring in the Wasatch Range, and more particularly of those in the Emma. With his permission, I insert here his remarks on the subject:

"The ores of the mines thus far opened in the Wasatch Mountains are largely composed of species resulting from the oxidation of sulphides, especially galenite and antimonial galena, with some salts of zinc and copper, all containing silver and rarely a little gold. Iron and manganese ochers occur in considerable quantity in some of them, but the process of oxidation has prevailed very extensively, so that the ochraceous character of the ores is the striking feature of most of the mines in this range.

"The great chamber of the Emma mine * * * was found to be filled almost exclusively with epigene species, the product of oxidation of sulphides, and capable of removal without the aid of gunpowder for the most part. The study of this mass reveals the interesting fact that it is very largely composed of metallic oxides, with but comparatively small proportions of carbonates and

[1] Raymond, R. W., op. cit., p. 325.

sulphates. Fortunately I am able to present an analysis of an average sample of 82 tons (183,080 pounds) of first-class ore from the Emma mine, made by James P. Merry, of Swansea, April, 1871, which is as follows, viz:

Silica	40.90
Lead	34.14
Sulphur	2.37
Antimony	2.27
Copper	.83
Zinc	2.92
Manganese	.15
Iron	3.54
Silver	.48
Alumina	.35
Magnesia	.25
Lime	.72
Carbonic acid	1.50
	90.42
Oxygen and water by difference	9.58
	100.00

"The quantity of silver obtained from this lot of ore was 156 troy ounces to the gross ton of 2,240 pounds.

"This analysis sheds important light on the chemical history of this remarkable metallic deposit and will aid us in the study of the paragenesis of the derived species. It is pretty certain that all the heavy metals have existed originally as sulphides, and we may, therefore, state the analysis thus, allowing 8.52 sulphur to convert the heavy metals to this state:

Silica	40.90
Metallic sulphides	52.60
Al, .35; $\dot{M}g$, .25; $\dot{C}a$, 72; $\dddot{M}n_3$; $\dddot{M}n$, .20	1.52
	95.02
Water, carbonic acid, and loss	4.95

"This calculation assumes that the sulphides are as follows, viz:

Galenite	38.69
Stibnite	3.30
Bornite	1.03
Sphalerite (blende)	3.62
Pyrite	5.42
Argentite	.54
	52.60

"This statement excludes the presence of any other gangue than silica, and considering that the ores exist in limestone, the almost total absence of lime in the composition of the average mass is certainly remarkable. The amount of silica found is noticeable, since quartz is not seen as such in this great ore chamber nor, so far as I could find, in other parts of the mine. The silica can have existed in chemical combination only in the most inconsiderable quantity, since the bases with which it could have combined are present to the extent of less than 1½ per cent; nor do we find in the mine any noticeable quantity

of kaolin or lithomarge, resulting from the decomposition of silicates, nor are there any feldspathic minerals. It is most probable that the silica existed in a state of minute subdivision diffused in the sulphides, as I have seen it in some of the unchanged silver ores of Lion Hill, in the Oquirrh Range.

"The absence of chlorine and of phosphoric acid in the analysis corresponds well with absence of the species cerargyrite and pyromorphite, of which no trace could be found by the most careful search among the contents of the mine. The miners speak of the 'chlorides,' and the unscientific observers have repeated the statement that silver chloride is found in the Emma mine, but the ores indicated to me as such are chiefly antimonic ochers.[1]

"The general (perhaps total) absence of the phosphates of lead in the Wasatch and Oquirrh mountains, so far as explored, is a striking peculiarity of the mineralogy of these ranges. On the other hand, the absence of chlorine in the mines of the two Cottonwoods and the American Fork is in striking contrast with the constant occurrence of cerargyrite (horn silver) in the Oquirrh and also in the southern extension of the Wasatch. I have sought in vain for a trace of this species in the districts of the Wasatch just named, and the occurrence of pyromorphite is extremely doubtful:

"Molybdic acid, however, exists pretty uniformly disseminated in the mines of the Wasatch in the form of wulfenite. Although it occurs in minute quantity, it is rarely absent, and may be regarded as a mineralogical characteristic of the districts of the two Cottonwoods and of the American Fork. For this reason a few particulars will be in place here.

"Wulfenite is found associated with calamine (smithsonite), cerusite, malachite, azurite, and more rarely alone in little cavities in the ochraceous ores. In the Emma mine vugs or geodes are occasionally found lined with botryoidal apple-green calamine, rarely crystallized, often brownish and sometimes colorless, but invariably associated with wulfenite. The calamine incloses and covers the crystals of wulfenite, which form a lining of considerable thickness. The wulfenite is in thin tabular crystals of a yellow color, resembling the Carinthian variety of this species. The crystals are very brilliant and perfect, but quite minute, rarely 2 or 3 millimeters in width and not over 1 millimeter in thickness, often less. They are quite abundant in this association, no piece of the calamine which I have seen being without them. They sometimes but rarely penetrate through the globules of the calamine so as to show themselves on the upper surface of that species. But the calamine has obviously formed botryoidal masses around the wulfenite, a crystal of this species being often seen forming the nucleus of the calamine globules.

"These facts are of interest in the paragenesis of these epigene species. The order of production has obviously been, first, the cerusite resting on ochraceous iron, manganese, and other metallic oxides; next, the wulfenite crystals were deposited upon and among the crystals of cerusite; and lastly came the calamine, crystalline at first and as it accumulated becoming fibrous and amorphous, completely inclosing and capping the other species.

"Wulfenite occurs also in this mine, as likewise in the Flagstaff, the Savage, and Robert Emmet, without the calamine, but never, as far as observed, without cerusite and other carbonates. In the Savage masses of cerusite, with various oxides, are interpenetrated by the tabular crystals of wulfenite.

[1] There exists generally among the mining population of the central Territories of the United States a distinction between horn silver and chloride of silver—an error arising, as I am persuaded, from supposing the ochraceous ores to be chlorides not so perfectly developed as to be sectile.

"Although wulfenite forms a very minute factor of the entire ore mass in these mines, by the law of mineral association it may be considered as the characteristic species of the ores of these districts, occurring in the magnesian limestones. So far as I am informed or have observed, wulfenite has not been hitherto found in any of the other mining districts of Utah; but by the same law it may be reasonably looked for whenever deposits of epigene minerals are explored in the same geological and mineralogical relations in the Wasatch Range of mountains.

"The oxidizing and desulphurizing agency which has acted upon the great ore mass of the Emma mine, whatever it was, has performed its work with remarkable thoroughness. A careful study of its action discloses some other facts of interest in the paragenesis of species. From the appearance of numerous large blocks of ore, forming solid bowlders in the general mass, a concentric arrangement is easily recognized. On breaking these masses across, the fresh fractures disclose a dark center which consists almost entirely of decomposed sulphides, composed chiefly of cerusite blackened by argentite and metallic silver in a pulverulent form. This dark center, chiefly of cerusite, is often pseudomorph of galenite in its fracture. Next is usually a zone of yellowish and orange-yellow antimonial ocher, cervantite, often quite pulverulent, at times only staining the cerusite; then follows a narrow zone of green and blue copper salts, malachite, azurite, cupreous anglesite, with, rarely, wulfenite; then follows cerusite, sometimes stained with antimony ocher, and not unfrequently associated with wulfenite; outside all are the iron and manganese ochers. This concentric arrangement I have observed in a great number of cases; and the above order of species, while not invariable, is believed to reflect accurately the general arrangement. Well-crystallized species, as mineralogical specimens, are rare in this great mass; but the following may be recognized as its chief components: *Galenite*, sphalerite, pyrite, jamesonite (?), argentite, stephanite, boulangerite (?), *antimonial galenite*, *cervantite*, mimetite (?), limonite, wad, kaolin, lithomarge, *cerusite*, anglesite, linarite, *wulfenite*, *azurite*, *malachite*, *smithsonite*. Those most abundant or best crystallized are in italics. This list can no doubt be extended as opportunity occurs for the more careful study of the ores, the great mass of which, amounting to many thousand tons, have gone into commerce without passing under any mineralogical eye."

After the exhaustion of the main ore bodies extensive prospecting was carried on, but with unsatisfactory results.

The Flagstaff mine was located and worked about the same time as the Emma and, like that, has long been idle. Huntley[1] gives the following description of the deposit:

The formation is the same mineral belt as the Emma. Ore came to the surface in one spot, and, following this indication a short distance, the discoverers came to the first and largest body. It was 400 feet long and 500 feet deep, extreme dimensions, and 3 feet wide. Some 20 or 30 other large-sized bodies were found, in all shapes and positions, usually near the hanging wall and invariably connected with one another by a small seam of ore or ocher. One body upon the footwall was joined to another near the hanging wall by a pipe of galena the size of a lead pencil.

The Vallejo and North Star claims are between the Flagstaff and Emma mines, but the occurrence of the ores seems to be somewhat

[1] Huntley, D. B., op. cit., p. 423.

different. Huntley[1] gives the following description of the ore bodies:

> The ore is found in irregular shoots or pipes near the hanging wall. Three bodies began near the grass roots, and others were found as depth was attained. At the period under review there were 10 shoots having a triangular or lenticular cross section and a uniform dip SE. 80°. These were from 20 to 100 feet apart and lay almost at right angles to the strike of the belt. The largest was 150 feet long, extreme dimensions from 6 inches to 10 feet wide, and had been followed 300 feet deep.

The rock formations in the Columbus Consolidated ground (now Wasatch mines) consist of the quartzite, the "lower white limestone," the Cambrian shale series, and some of the upper limestone series, together with granite prophyry dikes. The great overthrust fault of the district passes through the area and has cut off the lower portion of the great limestone series and formed the "lower limestone," while the Cambrian shale and quartzite have overridden this faulted portion. The rocks are also cut by several easterly fissures, one of the most prominent being the Braine fissure, which is connected with some of the largest bodies of ore thus far developed in the mine. The ore occurs both in fissure deposits and in bedded deposits, the latter being the more abundant. The bedded deposits occur where the easterly fissures cut certain sedimentary beds that appear to be especially susceptible to replacement. The trend of the deposits roughly follows the intersection of the bedding and the fissure, replacement extending to variable distances from the fissures.

Some of the larger deposits have been found near the contact of the "white limestone" with the underlying beds. There have also been important deposits in the shale series, apparently formed by replacement of a mottled blue and white calcareous member of the series. Other deposits occur at the contact of the "white limestone" with the overlying shale. The rocks have been broken and brecciated adjacent to the overthrust fault, and this has probably been a factor in rendering them especially susceptible to replacement.

In the lower levels the deposits are mainly sulphides, but it is reported that large bodies of oxidized ores were mined from the upper levels. The principal metallic minerals are pyrite, galena, sphalerite, and tetrahedrite, and the ores carry varying amounts of gold and silver. A specimen of tetrahedrite from this mine, as already noted, was found to contain several per cent of lead. Sphalerite is present in most of the ore but usually is not abundant. In the Garfield fissure a body relatively rich in sphalerite has been found but has not been extensively developed. At the time of visit, in 1912,

[1] Huntley, D. B., op. cit., p. 424.

most of the ore taken out from the lower levels was sulphide of milling grade, though the mine has yielded much shipping ore.

Bedded deposits have also been developed in the Columbus Extension mine, though as yet they have not been as important as the fissure deposits connected with the Toledo fissure, which is now included in that property.

The Alta Consolidated mine is near the head of Little Cottonwood Canyon, a short distance west of the City Rocks mine. The sedimentary rocks consist of the Cambrian shale and the overlying limestone, and the Clayton Peak stock of quartz diorite is but a few hundred feet to the south. The Cambrian shale at this point is considerably above the position that is indicated by its dip at the outcrop to the west, on the north side of the canyon, and has apparently been elevated by the entrance of the intrusive material and possibly by later faulting. The sedimentary series is cut by a strong easterly fissure having the prevailing strike and dip for the district.

The ore occurs both in fissure and bedded deposits, but the latter have thus far been the more productive. Deposits have been developed in the shale series (black lime) and near the contact of the shale and overlying limestone. In the shale the ore is largely sulphides—pyrite, galena, tetrahedrite, and some sphalerite. Quartz and muscovite (sericite) are the important gangue minerals. In the limestone the ores are largely oxidized, oxides of iron and manganese are abundant, and the principal valuable metals are lead, silver, and some copper. At the time of visit ore was being mined that contained a large percentage of a yellow earthy sulphate of iron and lead with some copper resembling beaverite.

BIG COTTONWOOD DISTRICT.

The Prince of Wales and other mines are just north of the Little Cottonwood divide on Silver Fork, a branch of Big Cottonwood Canyon. Like many of the other mines of the district they have long been idle. The Prince of Wales mine is apparently several hundred feet higher in the limestone series than the Flagstaff and Emma, and probably at about the horizon of the City Rocks mine. Huntley[1] gives the following description of the Prince of Wales deposits:

> The ore-bearing formation is said to be a bedded vein, dipping about 45° NW. in blue and white limestone. Four distinct chimneys or shoots of ore, 130 feet, 200 feet, and 260 feet apart, have been found. They occur where the limestone is white, metamorphic, and soft, while the barren spaces between

[1] Huntley, D. B., op. cit., p. 428.

these shoots contain the vein only as a narrow seam in hard blue limestone. These shoots outcropped at the surface, or were covered by a few feet of drift, as low-grade, ocher-stained seams of limestone and clay. Good ore was found by sinking a few feet. The Antelope and Prince of Wales shoot is from 2 inches to 4 feet (average, 12 inches) wide, 120 feet long, and has been followed on the dip 1,200 feet. The Highland Chief shoot is from 2 inches to 3 feet (average, 8 inches) wide, 75 feet long, and 800 feet deep. The Wellington shoots are each about from 2½ to 7 feet (average, 3 feet) wide, from 10 to 30 feet long, and 700 feet deep. The ore from the first assays about 140 ounces silver and 45 per cent lead; that from the second, 100 ounces silver and 40 per cent lead; and that from the third and fourth, 60 ounces silver and 50 per cent lead. The ore is a soft brownish-yellow ocher, containing argentiferous cerusite and galena and occasional stains of oxides of manganese and copper. The mine is opened by several tunnels, the main one being 2,200 feet long and running on the vein entirely through the ridge, and a 1,100-foot incline, on which there are hoisting works, on the crest of the ridge. The cuttings are said to be 1,300 feet in extent.

The large ore body of the Cardiff mine, opened by the lower tunnel in October, 1914, doubtless belongs to the bedded type of ore bodies. It lies in the "lower limestone" below the overthrust and is said to be connected with a mineralized fissure, but it is not known whether or not this fissure corresponds to the vein worked through the upper tunnel, 300 feet above the lower. (See p. 204.) According to the latest information, the large ore body has been opened 250 feet along the strike and crosscuts show a width reaching 100 feet along the dip. Ore has been followed more than 200 feet above the tunnel by raising, while a winze has been sunk 90 feet below it. Shipments of about 90 tons daily are being made. Hauling costs about $4 a ton. Up to about August 1, 1915, shipments amounted to 3,420 tons, valued at $145,350.[1] The ore contains silver and lead, with some copper.

Other bedded deposits in the Big Cottonwood district, such as those in the Maxfield, Reed and Benson, and Carbonate (Kessler) mines, were not accessible in 1912, but an idea of their character may be gained from the following descriptions quoted from Huntley:[2]

The Maxfield is situated a quarter of a mile northwest of Argenta and 14 miles east of Sandy, in a side ravine, and near the bed of the main canyon. It is owned by the Maxfield Mining Co., of Salt Lake City, incorporated in March, 1879. This company also owns the extensions or parallel claims Vinnie, Amanda, Red Pine, Tyler, and Fairview. These are mostly patented but only slightly developed. The Maxfield is a bedded vein, from 1 to 8 feet wide, dipping 45° NE., between strata of a compact bluish-white limestone. The ore occurs usually upon the footwall, in one chimney 200 feet long and 2 feet wide. It is a soft brown ochery carbonate and galena, assaying from 30 to 100 ounces. On the hanging wall there was a band of quartz, from 3 to 8 inches wide, containing galena and pyrites. When carefully sorted this yields good ore.

[1] Eng. and Min. Jour., July 24, 1915, p. 167; Aug. 14, 1915, p. 291.
[2] Huntley, D. B., op. cit., pp. 427–430.

The mine is dry and has been developed 75 feet vertically and 212 feet horizontally by a tunnel on the vein from the bed of the ravine. The total openings aggregate 800 feet.

The Maxfield mine was worked up to 1905, but to what extent is not known. In 1905 it became flooded with water, and extensive operations ceased. Since then lessees have produced some lead ore each year.

The Reed and Benson mine is situated on a spur of the Cottonwood divide, between Day's and South forks, 11,000 feet above sea level and 2½ miles northwest of Alta. It was located in 1870 and was worked vigorously from September, 1871, until April, 1878. Since then it has been idle or leased to a very limited extent. This mine is supposed to be upon the same mineral belt as the Flagstaff and the Emma. The belt at this point is about 200 feet wide. The ore occurs in a vein or chimney on the hanging-wall side and in about 20 irregular lenticular bodies, which branch at all angles from the chimney, on its footwall side. These do not, as a rule, extend more than 75 feet from the main chimney and vary from 6 inches to several feet in width. One outcropped as a low-grade ocher. The largest is about 170 feet from the surface. The ore is of the kind usually found in this limestone formation, namely, a yellow and red oxide of iron carrying argentiferous cerusite and galena. It is claimed that the total shipments have averaged 120 ounces silver and 35 per cent lead per ton. The mine is developed by a 380-foot tunnel, in which there is a whim on a 400-foot incline, dipping 35° NNE. Below this there are four windlasses, which carry the incline down 400 or 500 feet deeper. In general the mine may be said to have been opened from the surface 1,100 feet on the dip (35°) by an irregular incline following the chimney. Near the surface the ore extended 100 feet and the workings 200 feet horizontally; but in the bottom of the incline not over 40 feet of drifting have been done. The openings have a total length of 1,950 feet.

The Ophir is a few hundred feet southwest of the Reed and Benson. * * * It was discovered in 1870, purchased by Reed & Goodspeed in 1871, leased until May, 1878, and worked steadily since by about 10 men. Ore is found in three bodies in a 30-foot stratum of compact dark-blue limestone. A stratum of white limestone above carries no ore. The outcrop was a pipe 2½ feet in diameter of low-grade ocher. The shape of the bodies is that of a flattened or an elongated ball, the largest being 50 by 20 by 15 feet. They are 4 and 10 feet apart and not over 50 feet from the surface. At the period under review drifting was being carried on upon a seam of ocher in the expectation of finding another body. The total cuttings did not exceed 700 feet. During the census year 173 tons of ore similar to that of the Reed and Benson, excepting that it was of lower grade, assaying only about 45 per cent lead, 42 ounces silver, with 3 per cent moisture, were sold for $8,581. The previous product was estimated at $22,000.

The mine of the Kessler Mining Co. covers part of the ground of the old Provo claim. It was worked by a New York company in 1872, 1873, and 1874. Little ore was obtained, and it was abandoned. About 1875 a prospector discovered the carbonate ore body while overhauling the old dump, so says tradition. The mine was bought by the Carbonate Co., of Salt Lake City, which extracted large quantities of ore. In January, 1879, after the large discovery ore body had been nearly all extracted, the mine was sold to the Kessler Mining Co., of New York City. This company took out considerable ore and did much

prospecting but ceased work some months previous to the writer's visit, at which time the mine was worked by a few lessees. The property consists of the following overlapping unpatented claims: Carbonate (1,500 by 200 feet), Little Giant, Sailor Jack, Alturas, Baker, and Defiance. These are situated on the summit of the ridge of Silver Mountain, about 11,000 feet above sea level, 3 miles south of Argenta, and about 6 miles northwest of Alta. * * * The ore is found in several bodies near the surface on the hanging-wall side of a stratum or belt of limestone. The largest body was just below the surface and was lenticular in shape, its dimensions being 200 by 100 by 50 feet. It was timbered by 365 square sets but had caved in. The gangue, if such it may be called, which surrounds the bodies and also serves as a connecting link between them, consists of a valueless ocher or limonite. It is very abundant, sometimes fine and soft; at other points hard and siliceous. Occasionally heavy spar, oxide of manganese, and stains of malachite are found. The ore is an ocher, containing cerusite and galena, and assays from 30 to 50 per cent lead and from 30 to 100 ounces silver. A fissure vein, called the "Sailor Jack," connects with this body and has been the cause of much litigation. There is also a vertical fault of 500 feet. The mine is opened 950 feet horizontally and 300 feet vertically below the croppings by six tunnels and one incline shaft. Four of the tunnels and the shaft are upon the fissure vein. The cuttings are 5,500 feet in length. The mine is dry, excepting from surface water from melting snows in the spring. * * * During the census year 692 tons were produced, which sold for $16,554.74. The total product of the mine prior to October, 1877, is estimated at $120,000. Between the above date and the beginning of the census year 4,549 gross tons, averaging about 8 per cent moisture, were sold for $261,044.41.

Bedded deposits are also reported from other localities which were not examined and of which no description has been found.

AMERICAN FORK DISTRICT.

The only bedded deposits in the American Fork district are those of the famous old Miller mine, on Miller Hill, just east of the divide between the head of American Fork canyon and Mary Ellen Gulch. This mine was the cause of great activity in the early seventies. According to Huntley,[1] it "was discovered in 1870 and was sold the following year for $120,000 or over." The mine was examined by J. P. Kimball in 1872 and the following data are abstracted from his published report, lent to the writers by W. A. Wilson, of Salt Lake City, the present manager:

The earliest workings, as early as 1872, were inaccessible. The "vein" then worked followed the bedding, which dips 15°-25° SE. It lies near the base of the limestone series. The ore cropped out on the southwest side of the hill and was followed along the footwall for about 120 feet, when it "rolled" downward for a short distance and again followed the bedding. Below the roll (at the Car tunnel) the "vein" was 17 feet thick. The footwall was clearly defined, but the

[1] Huntley, D. B., op. cit., pp. 444-445.

top of the ore body graded into the limestone. The footwall was a bed of "tight lime" with a streak of clay selvage marking the contact with the ore. The hanging wall was shaly, much fractured, and partly altered to "ocherous matter." Fragments of the hanging-wall rock were found throughout the vein. The east side of the old incline showed either a steep pitch, a horse of loosened rock, or a fault causing the abrupt disappearance of the vein material on this side. Not enough work had been done at the time to determine the structure.

Quartz and calcite were generally absent, except as "a residue of country rock." The ore minerals were galena, cerusite, and "plumbic ocher," all carrying silver. Considerable hydrous ferric oxide was present, presumably an alteration product of pyrite, and the green and blue stains of copper carbonate were found in drusy cavities in the hanging wall. Black manganese stains were commonly present with the iron oxide.

Cerusite was the most abundant of the three lead minerals. It included two varieties, black and white. The black variety, in contrast to the white, probably owed its color, in Kimball's opinion, to finely divided silver sulphide and was the rich ore of the mine, "containing 83 per cent lead along with some 76 ounces of silver to the ton." This black variety must have been largely galena, for pure cerusite contains only 76 per cent of lead, whereas galena contains 86 per cent. It occurred in granular masses in the lower and middle parts of the "vein." Some of the masses were 1 to 6 feet in diameter and comprised from 10 to 16 per cent of the total ore shipped. The white variety, carrying about 60 ounces of silver to the ton, was the predominant ore and in a concentrated form occupied the lower half of the ore body. It was arranged in lenticular layers, separated by thin seams of clay and "plumbic ocher." "Perfectly pure lenses" of it were present, from 3 to 5 feet thick and having the consistency of quicksand. The "plumbic ocher" occurred in irregularly distributed masses or lenses in the lower part of the vein and carried as much as 36 ounces of silver and 2.45 ounces of gold to the ton. Some gold was also present in the ferric oxide. The upper part of the "vein" consisted of brecciated limestone and ferric oxide, the former more or less impregnated with copper salts and partly oxidized galena. The ore body, according to Kimball's report, was said to be the largest deposit of lead carbonate then known, but much larger bodies have since been developed in other districts.

The following table of assays, taken from Kimball's report, represents the western ore bodies of the mine, worked up to 1872:

Assays of ore from Miller mine.

Kind of ore.	Lead.	Silver.	Gold.
	Per cent.	*Oz. to the ton.*	*Oz. to the ton.*
Galena	56	25.51	0.30
Do	70	38.88	.60
Do	64	125.97	None.
Do	62	45.20	.43
Gray [white?] carbonate and galena	75	34.62	.75
Gray [white?] carbonate	60	30.37	.60
Black carbonate	68	38.45	Trace.
Do	72	36.57	Trace.
Carbonate	75	35.07	2.34
Do	83	31.49	2.77
Oxide of lead	(a)	25.8	(b)
Third-class vein matter	40	16.96	None.
Run of mine	58	29.16	.50
Do	53	27.32	.60
Do	60	30.37	.60
Do	57	33.41	.60
Do	55	36.00	(b)

a Not determined. b Included in silver.

The average value per ton of base bullion produced from these ores at the old Sultana smelter in American Fork Canyon for 60 working days was as follows: Lead, \$140.70; silver (60.36 ounces), \$86.47; gold (0.97 ounce), \$22.27; total, \$249.44.

According to Huntley,[1] there were in 1880 ten tunnels, four shafts, and 10,000 feet of openings, exclusive of stopes, in the Miller mine. The deepest workings were 600 feet below the hilltop and extended horizontally 900 feet. Ore was found in six or eight large bodies which began within 70 feet of the surface in a belt of dolomite. About 4,800 tons was extracted from the largest body. In addition to the minerals mentioned by Kimball, wulfenite was present in the oxidized ore and a little zinc blende and pyrite were found below water level (500 feet). The total production of the old workings was estimated to have been between 13,000 and 15,000 tons, assaying 40 to 54 per cent of lead and 30 to 47 ounces of silver and \$2 to \$10 in gold to the ton. These figures do not range as high as some of those given by Kimball.

The old ore bodies gave out and the company ceased operations in December, 1876, and since that time the mine has been worked by lessees. No great amount of ore was produced until 1905, when the Tyng Bros., then leasing, opened another large body, which replaced the limestone along a nearly due east fissure for a total distance of over 400 feet and was 10 to 40 feet wide. The increased production from 1905 to 1908 was due to this deposit. The rock replaced was a gray dolomite (?), overlain and underlain by shaly limestone. Two other

[1] Huntley, D. B., op. cit., pp. 444–445.

bodies, smaller and less regular, were found about 100 feet north of the main body, one on each side of a porphyry dike, whose strike is about N. 70° E. The main ore body ended abruptly on the east, possibly against a fault, and a search has recently been made for its eastward continuation, but up to 1913 only relatively low grade oxidized ore had been found. The ore was principally rusted "sand carbonate" containing residual bowlders of galena. It also contained copper stains, but assayed less than 2 per cent copper. The average content of the ore shipped from the Tyng lease was 0.98 ounce of gold and 21.72 ounces of silver to the ton, 39.29 per cent of lead, 4.90 per cent of zinc, 20.17 per cent of iron, 2.61 per cent of sulphur, and 3.56 per cent of insoluble. These figures show that the ore was mostly oxidized and contained very little quartz or barite gangue.

DEPOSITS IN THE ALPINE DISTRICT.

The Alpine mining district is in the foothills of the Wasatch Range, north and east of the town of Alpine, which is about 5 miles north of the town of American Fork. It includes the southwestern part of the granodiorite stock of the Cottonwood region and a considerable part of the great limestone series. Cambrian quartzite is also present but not closely related to either of the two properties examined.

The only fissure deposit in igneous rock examined in the region covered by this report is that of the Lucky Chance mine, about 3 miles north of Alpine. Here the country rock is typical granodiorite of the Little Cottonwood stock. The ore occurs in shear zones along which the rock has developed a highly schistose structure. The shear zones strike N. 60° E. and N. 80° W., with northward dips of 30° to 60°, and appear to be grouped in a belt of north-northeastward trend, 100 feet or more wide and of unknown length.

The mineralized rock consists principally of quartz that fills openings and more or less completely replaces the sheared rock, which is colored dark green by micaceous alteration minerals. The ore minerals are pyrite and galena. The deposits range from thin sprinklings along a fracture to well-defined lenticular veins as much as 1 foot wide and 20 feet long.

In thin section the moderately mineralized rock consists mostly of much shattered feldspar and quartz. The feldspars are traversed by veinlets of sericite and calcite, and the quartz areas by veinlets of minutely granular quartz. Chlorite is present in small drawn-out aggregates, representing the original biotite of the rock. Pyrite is present in small grains closely associated with the sericite and quartz veinlets. The absence of magnetite suggests that its iron, with prob-

ably some from the biotite, has gone to form the pyrite. The sericite (if it is all of the potash variety) implies an introduction of some potash to replace the soda and lime of plagioclase, but the principal materials introduced appear to have been water, carbon dioxide, and a little sulphur.

The more completely mineralized rock in thin section shows the same character, but the feldspar and chlorite are nearly all replaced and the quartz is nearly all recrystallized. Secondary quartz is abundant and sericite subordinate. Galena is present with the pyrite. Both ore minerals form aggregates, confined principally to the network of veinlets but also sending short branches into the inclosing minerals. The quantity of replacing minerals in this rock shows that silica, iron, and lead, as well as sulphur, water, and carbon dioxide, were introduced. Sericitization, characteristic of the less intense alteration, is here overshadowed by silicification.

A small shipment of ore was made from this mine a few years ago. It ran well in silver and comparatively well in gold.

The only deposit in the limestone of the Alpine district visited by the writers is on the Alpine-Galena property, near the mouth of Boxelder Canyon, northeast of Alpine. The country rock is near the base of the great limestone series and is probably of Cambrian age. The only ore found up to 1912 was in small masses of silver-bearing galena and lead carbonate along a bedding plane. The bedding plane had been followed down about 50 feet to a small body of leached replacement quartz, originally pyritic.

The mineralization in the Alpine district, so far as disclosed both in the Lucky Chance and in the Alpine-Galena ground, was of the same character as that in the productive mines of the Cottonwood-American Fork region, but the amount was decidedly small.

GENESIS OF THE ORES.

A detailed discussion of the genesis of the ores of the region will not be given in this place, but certain facts bearing on this subject will be pointed out and the general conclusions reached will be stated.

As has been shown in the discussion of the main types of deposits—contact, fissure, and bedded deposits—there is no doubt that they are of common origin, showing complete mineralogical gradation. At several places contact deposits pass into fissure deposits, and as a rule the classification into fissure and bedded deposits is based on form rather than on any inherent difference in the character of the mineralization.

The deposits in the igneous rocks, so far as shown by present developments, are of little importance in this region, and their relation

to the deposits in the adjacent sedimentary rocks is not as clearly shown as in other districts of the State. The mineralization in the igneous rocks, however, is such as might have been effected by the same solutions that produced the deposits in the sedimentary rocks.

The source of the metal-bearing solutions is believed to have been the igneous material that forms the stocks in the region. This is indicated by the location of the deposits and also by the character of the mineralization. A glance at the geologic map (Pl. VI) will show that the principal mineralized areas of both the Cottonwood-American Fork and the Park City regions are grouped around the Clayton Peak stock. They are associated with fissures that were apparently formed at the time of the intrusion of the stocks. This grouping in itself suggests that the ore-bearing solutions were derived from the intrusive material. Moreover, the aplitic and pegmatitic dikes or veins which were evidently late phases of the igneous activity, contain sulphides and locally diopside in notable amount, and this naturally suggests that the solutions which escaped from the igneous bodies carried ore-forming materials. The association of diopside and pyrite, both in the aplitic veins and in the contact deposits, is especially suggestive. The deposits, notably the contact deposits, are similar in character to those of other districts where their origin from solutions given off from igneous material is pretty definitely established. Of particular significance in this connection is the boron mineral ludwigite, as the boron minerals are commonly regarded as indicative of igneous origin.

The deposits in this region are in many respects similar to those of the Park City district, which have been carefully studied by Boutwell and which he concludes are genetically related to the intrusive rocks.[1] There are, however, differences between the deposits of the two areas that should not be overlooked. It is commonly stated in newspaper and other descriptions of the Cottonwood region that the ore deposits occur in the same formations as those of the Park City district, a statement with no basis in fact, for the deposits of the Park City district are all in the Weber quartzite and higher formations, while the known deposits of the Cottonwood area are, with few exceptions, in formations below the Weber quartzite. A comparison of the deposits at different horizons in the stratigraphic series gives this fact added significance. Around and closely associated with the Little Cottonwood stock of granodiorite, intruded into the pre-Cambrian and early Cambrian rocks, few, if any, deposits of commercial importance have been developed, while most of the important deposits of the belt are associated with the Clayton Peak stock of quartz diorite, intruded into

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[1] Boutwell, J. M., op. cit., p. 128.

Paleozoic and Mesozoic rocks. Moreover, viewed in a general way, with due regard for structural features and differences in character of rock which have been important factors in the deposition of the ores, there is a general increase in mineralization from the lower to the higher formations, the ore bodies in the late Paleozoic and early Mesozoic rocks of the Park City district being far more valuable than any known in the earlier rocks of the Cottonwood area.

It is needless to say that this statement does not imply that valuable deposits do not exist in the Cottonwood-American Fork region, for several such deposits have been developed; but, so far as known, they are neither so large nor so continuous as in the Park City district.

A study of the ore deposits of the State[1] indicates that as a general rule the greatest mineralization occurs toward the top of intrusive stocks or in the adjacent sedimentary formations at a corresponding horizon, and therefore it is not probable that the mineralization in the Cottonwood-American Fork area was as extensive as that in the Park City district.

[1] Butler, B. S., Relation of ore deposits to different types of intrusive bodies in Utah: Econ. Geology, vol. 10, p. 101, 1915.

POTASH IN CERTAIN COPPER AND GOLD ORES.

Compiled by B. S. Butler.

COPPER ORES.

INTRODUCTION.

The amount of copper ore that is treated by concentrating methods has rapidly increased during the last few years and now exceeds 30,000,000 tons a year. Probably 25,000,000 tons of western copper ores are now annually treated by this process. Any commercial use that might be made of the tailings from such treatment would be of prime importance. In the past the Survey, in its study of these deposits, has collected a large amount of information concerning the composition of the ores, much of which has recently been published for the first time.[1] An inspection of these analyses shows the fact well known to students of the deposits, that the ores are relatively rich in potassium.

In the treatment of the ores for the recovery of the metals contained they are finely ground. If the recovery of potash from silicates should ever become a commercial possibility it would seem that the tailings from these ores are in a condition well suited to cheap treatment and would furnish a very large supply. They are, moreover, accessible to transportation facilities and in many places to moderately cheap supplies of electric power, water, etc., that have been provided for recovering the metal content of the ores. The recovery of potassium from silicates has received much attention in recent years, but no commercially successful method has yet been put into operation. The large and cheap supply of such material, however, is certain to encourage further investigation. It seems reasonable to suppose that in the treatment of ores in which the potassium occurs in the mineral muscovite, the muscovite will tend to collect in the finer material or "slimes," and these finer tailings may be considerably higher in potassium than the coarser material. If they are, it may be to the interest of the companies to impound separately the fine and coarse tailings.

In the following pages have been brought together portions of some complete analyses of copper ores from different districts showing the potash content and the percentages of the commoner oxides.

[1] Clarke, F. W., Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1880-1914: U. S. Geol. Survey Bull. 591, 1915.

For each district are given the amount of ore available and the quantity that has been treated. The last item gives an approximation of the amount of tailings that have resulted from past operations.

For the convenience of the reader wishing to examine the full analyses in the original publications, the letters designating the excerpts from the analyses are those used in the publication from which they were taken.

BINGHAM DISTRICT, UTAH.

B, C, D, Mineralized monzonite porphyry, collected by J. M. Boutwell from British tunnel, Last Chance mine, and described in Professional Paper 38, page 178. E. T. Allen, analyst.

E, F, Altered porphyry, collected by B. S. Butler, who supplies the petrographic data. George Steiger, analyst. E, Dark ore; contains biotite, orthoclase, muscovite, rutile, and quartz. F, Light ore; contains quartz, orthoclase, muscovite, rutile, and very little biotite.

[From Bulletin 591, p. 146.]

	B	C	D	E	F
SiO_2	56.78	56.17	58.64	63.09	66.27
Al_2O_3	16.90	15.94	15.35	16.33	15.01
Fe_2O_3	6.87	3.43	3.25	1.37	1.84
FeO	2.34	1.92	2.54	3.29	.39
MgO	.03	1.60	3.84	3.53	.71
CaO	1.18	5.19	5.37	.70	.18
Na_2O	.37	2.48	3.60	2.79	.72
K_2O	7.02	4.91	4.23	3.91	9.62

These analyses represent rocks that have undergone the alteration that has accompanied the deposition of ore minerals. The composition of the ore mined is probably most nearly represented by analyses E and F. Mineralogically the ores differ considerably, but potash is present in the minerals muscovite, biotite, and orthoclase, in varying amounts. Analysis F, the one highest in potash (K_2O), represents a specimen of the "light ore," in which much of the potassium is in the mineral orthoclase.

By churn drilling and other means of exploration, 377,690,400 tons of ore of this type, of which 35,190,400 tons had been mined and milled, had been developed in this district to the end of 1914.

Samples of tailings from the mill of the Utah Copper Co. were examined in the laboratory of the Survey by R. C. Wells with the following results: Sand vanner tailings, 6.81 per cent K_2O, 0.53 per cent Na_2O; slime vanner tailings, 5.88 per cent K_2O, 0.56 per cent Na_2O.

SAN FRANCISCO DISTRICT, UTAH.

Altered quartz monzonite, collected by B. S. Butler and described in Professional Paper 80. C, O K mine; D, Cactus mine. R. C. Wells, analyst.

[From Bulletin 591, p. 148.]

	C	D
SiO_2	66.87	62.56
Al_2O_3	18.14	17.21
Fe_2O_3	1.36	2.29
FeO	1.06	3.64
MgO	.68	1.13
CaO	.11	.29
Na_2O	.61	.07
K_2O	4.12	6.02

These are analyses of ores. The tailings dump from the Cactus mill is estimated to contain over 500,000 tons of material.[1] The potassium in this ore is in the mineral muscovite.

SANTA RITA DISTRICT, N. MEX.

Rock from the Santa Rita mine, 300-foot level. W. T. Schaller, analyst.

[From Professional Paper 68, p. 39.]

SiO_2	65.15
CaO	1.96
Na_2O	2.81
K_2O	5.52

No series of analyses that can be said to represent the ore has been published.

The ore consists of mineralized igneous and sedimentary rocks The sedimentary rocks (quartzite, limestone, and shale) originally contained little or no potash, and it is reasonable to suppose that in the mineralization they did not become as rich in this material as the igneous rocks, which contained several per cent of potash before mineralization. It seems likely, then, that this deposit as a whole is not so rich in potash as some deposits formed in rocks all of which carried potash before mineralization.

A sample of the "slime" produced at the Hurley plant of the Chino Copper Co., where the ores from the Santa Rita district are treated, was examined in the laboratory of the Survey and found to contain 4.42 per cent of potash (K_2O).

To the end of 1914 there had been developed in this district 95,300,000 tons of ore, of which 5,012,800 tons had been milled.

[1] Bur. Mines Tech. Paper 90, p. 18, 1915.

RAY DISTRICT, ARIZ.

Rocks collected from mines of Ray Consolidated Copper Co. by F. L. Ransome, who supplies the petrographic data. R. C. Wells, analyst.

G. Metallized Pinal schist, "primary ore," Ray mine. Contains quartz, sericite, chlorite, biotite, pyrite, chalcopyrite, pyrrhotite, and zircon.

H. Altered Pinal schist, "primary ore," No. 1 mine, 2,075-foot level.

I. Altered Pinal schist, enriched ore, No. 1 mine, 1,940-foot level.

J. Altered Pinal schist, "primary ore," No. 2 mine, 2,190-foot level.

K. Altered Pinal schist, enriched ore, No. 2 mine, 1,925-foot sublevel.

[From Bulletin 591, p. 154.]

	G	H	I	J	K
SiO_2	78.91	68.00	68.44	71.05	68.95
Al_2O_3	10.76	16.56	15.34	13.49	12.88
Fe_2O_3	.87	.79	.36	.45	None.
FeO	1.57	1.73	1.33	1.15	1.12
MgO	1.66	1.04	.21	.41	.34
CaO	.25	.27	.07	.17	.18
Na_2O	.16	.73	.41	.31	.80
K_2O	3.44	5.37	5.74	3.80	4.99

The potash present is in the mineral muscovite (sericite).

On December 31, 1914, the known ore reserves of this district amounted to 74,765,789 tons, and 7,061,821 tons of ore had been mined and milled.

MIAMI DISTRICT, ARIZ.

Pinal schist, the so-called "primary ore," collected by F. L. Ransome. Chase Palmer, analyst.

A. 420-foot level, Miami mine.

B. 570-foot level, Miami mine.

C. 3,480-foot level, Scorpion shaft.

D. 3,350-foot level, Joe Bush shaft.

[From Bulletin 591, p. 154.]

	A	B	C	D
SiO_2	70.63	63.04	63.70	66.92
Al_2O_3	14.02	17.82	19.53	19.23
Fe_2O_3	2.73	2.26	3.46	1.09
FeO	.72	.89	1.36	.45
MgO	.70	.58	1.60	.97
CaO	.13	.13	.41	.27
Na_2O	.41	.62	.46	.39
K_2O	4.93	6.58	5.08	5.61

The potash in these ores is in muscovite.

At the end of 1914 there were known ore reserves in the district amounting to about 133,000,000 tons, and about 3,650,000 tons had been milled.

MORENCI DISTRICT, ARIZ.

Rocks collected by Waldemar Lindgren and described in Professional Paper 43, p. 168. W. F. Hillebrand, analyst.

B. Altered porphyry, Ryerson mine. 100-foot level.

C. Altered porphyry, chalcocite zone, Humboldt stopes.

D. Surface alteration of altered porphyry, Copper Mountain.

E. Primary silification of porphyry, Ryerson mine.

[From Bulletin 591, p. 156.]

	B	C	D	E
SiO_2	46.67	64.88	72.78	69.55
Al_2O_3	20.92	16.41	15.35	16.43
Fe_2O_3	.37	.65	.55	.46
FeO	.36		.10	.11
MgO	.85	1.12	.89	.62
CaO	.15	.11	.14	.15
Na_2O	.16	.12	.36	.17
K_2O	4.33	4.96	5.00	5.05

The potash in these deposits occurs in the mineral muscovite.

There are large ore reserves in this district. In the five years 1910 to 1914, inclusive, more than 7,000,000 tons of ore was concentrated in the district, and this together with earlier operations has resulted in the accumulation of a large quantity of tailings.

ELY, NEV.

Rocks collected by A. C. Spencer.

B. Altered monzonite, Veteran mine. The plagioclase is partly changed to sericite. Also contains biotite, orthoclase, quartz, and pyrite. George Steiger, analyst.

F. Enriched ore, bottom of Copper Flat mine. Original plagioclase destroyed by sericitization. George Steiger, analyst.

G. Ore, west side of Copper Flat mine. Plagioclase replaced by sericite; orthoclase not attacked. Quartz and sulphides added. R. C. Wells, analyst.

H. Ore material after complete oxidation, west side of Copper Flat mine. Composed mainly of quartz and sericite, with some orthoclase and kaolin. R. C. Wells, analyst.

I. Sulphidized monzonite, shaft of Ely Central Co. George Steiger, analyst.

[From Bulletin 591, p. 162.]

	B	F	G	H	I
SiO_2	64.11	64.73	74.62	80.58	60.37
Al_2O_3	16.52	14.41	10.23	8.51	15.96
Fe_2O_3	.41	None.	....	1.15	.51
FeO	1.07	.53	.55	Undet.	1.80
MgO	1.85	.76	.83	None.	1.63
CaO	1.00	.44	Trace.	.15	4.12
Na_2O	1.64	.70	.33	.41	3.12
K_2O	8.26	7.84	6.57	5.33	5.07

The potash in these ores occurs in the minerals muscovite, biotite, and orthoclase.

To the end of 1914 more than 75,000,000 tons of ore had been developed, of which more than 15,000,000 tons had been milled.

BUTTE DISTRICT, MONT.

Altered Butte granite, collected by W. H. Weed and G. W. Tower, and described in Professional Paper 74.

I. Decomposed near quartz-pyrite veins. Shows opaline silica, with sericite derived from feldspar. Hornblende gone; mica recognizable only as sericite masses having the form of biotite. H. N. Stokes, analyst.

J. 300-foot level, Colusa mine. Contains quartz, altered orthoclase and plagioclase, and sericite. E. T. Allen, analyst.

K. Wall rock, 1,300-foot level, Parrot mine. Contains quartz, sericite, pyrite, bornite, etc. E. T. Allen, analyst.

L. Enargite vein, 1,000-foot level, Leonard mine. Contains quartz, kaolin, pyrite, etc. W. F. Hillebrand, analyst.

M. Veinlets in Original mine. Contains quartz, sericite, partly altered feldspars, calcite, zinc blende, etc. W. F. Hillebrand, analyst.

[From Bulletin 591, p. 94.]

	I	J	K	L	M
SiO_2	64.81	56.80	62.09	66.90	54.30
Al_2O_3	19.44	21.02	15.40	15.83	13.63
Fe_2O_3	1.82	3.06	8.52	(?)	1.89
FeO	.16	.90	....	(?)	2.22
MgO	.19	1.21	.42	Trace.	2.13
CaO	.18	.35	.20	.05	7.36
Na_2O	.21	.50	.37	.08	.16
K_2O	5.30	4.78	4.34	.03	4.41

Potash is present in the mineral muscovite.

The Butte district contains large reserves of concentrating ore. During the last 10 years the district has made an annual output of ore ranging from 3,700,000 to 5,600,000 tons. As a large part of this ore was concentrated it is evident that these and earlier operations have resulted in the accumulation of millions of tons of tailings.

GOLD ORES.

The ores of several of the large gold-producing districts of the West are notably rich in potassium, and although the tonnage in these deposits is usually small compared with that of the copper deposits, nevertheless in several places there have been large accumulations of tailings. It is probable that the analyses quoted below, all of which were made for other purposes than the determination of the potash content of the ore, give a less accurate idea of the potassium content of the material as actually mined and milled than the analyses of the copper ores. Some facts concerning a few of the larger districts are given in the following paragraphs.

CRIPPLE CREEK DISTRICT, COLO.

Altered latite-phonolite.

A. Washington shaft, Stratton's Independence mine. Collected by Whitman Cross. W. F. Hillebrand, analyst.

C. Level 11, vein No. 3, Vindicator mine. Collected by Waldemar Lindgren and F. L. Ransome. W. T. Schaller, analyst.

[From Professional Paper 54, p. 189.]

	A	C
SiO_2	56.74	57.91
Al_2O_3	20.30	....
Fe_2O_3	1.06	....
FeO	....	....
MgO	.23	.33
CaO	.57	.81
Na_2O	.62	.45
K_2O	13.36	13.35

Breccia from Golden Cycle mine. Collected by Waldemar Lindgren and F. L. Ransome. W. T. Schaller, analyst.

[From Professional Paper 54, p. 192.]

SiO_2	54.57
CaO	2.79
MgO	1.06
Na_2O	3.85
K_2O	7.50

Fresh and altered granitic rock from level 6, Ajax mine, B 1 foot from A. Collected by Waldemar Lindgren and F. L. Ransome. W. F. Hillebrand, analyst.

[From Professional Paper 54, p. 194.]

	A	B
SiO_2	66.20	59.58
Al_2O_3	14.33	16.00
Fe_2O_3	2.09	.30
FeO	1.93	.65
MgO	.89	.03
CaO	1.39	2.03
Na_2O	2.58	.96
K_2O	7.31	11.93

During the period 1904 to 1914, inclusive, the Cripple Creek district produced 7,796,000 tons of ore. As most of this was milled, it is evident that a large accumulation of tailings has resulted.

GOLDFIELD DISTRICT, NEV.

The rocks of the Goldfield district, Nev., contain potassium in the form of alunite, but so far as indicated by available analyses [1] the percentage of potassium in the ores is not very high.

To the end of 1914 the Goldfield district had produced about 2,400,000 tons of ore, a large part of which was treated in the mills of the district.

[1] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, 1909.

TONOPAH DISTRICT, NEV.

Rocks collected by J. E. Spurr and described in Professional Paper 42.

C. Kaolinic alteration of hornblende andesite, from a pit in the saddle between Halifax shaft and the Mizpah mine. Entirely altered to quartz, kaolin, and muscovite. George Steiger, analyst.

D. Hornblende andesite, altered to chlorite and calcite; Mizpah shaft, 675 feet down. Contains chlorite, calcite, a little quartz, feldspar, sericite, hematite, zircon, and apatite. George Steiger, analyst.

E. Hornblende andesite, partly altered to orthoclase (?), Mizpah Hill. Ferromagnesian minerals completely decomposed. Some secondary quartz is present. George Steiger, analyst.

F. Hornblende andesite altered to quartz and muscovite, Mizpah vein. Little more than quartz and muscovite can be made out. George Steiger, analyst.

G. Early andesite, hanging wall of vein, 300-foot level, Mizpah mine. A more advanced stage of quartz-muscovite alteration than F. George Steiger, analyst.

H. Extreme stage of alteration of andesite to quartz and muscovite, west drift, Mizpah vein. Quartz, with much muscovite. George Steiger, analyst.

J. Pyroxene-biotite andesite, completely decomposed, Montana-Tonopah shaft. Feldspars entirely altered to calcite, sericite, and quartz. Biotite and hornblende altered to chlorite, calcite, quartz, sericite, siderite, and pyrite. George Steiger, analyst.

M. Biotite-pyroxene andesite, North Star shaft. Entirely altered. Feldspar altered to calcite. Pyrite, siderite, and rutile are present. George Steiger, analyst.

[From Bulletin 501, pp. 158, 159.]

	C	D	E	F	G	H	J	M
SiO_2	71.14	55.60	73.50	72.98	76.25	91.40	57.51	51.64
Al_2O_3	15.24	16.70	14.13	14.66	12.84	4.31	16.55	15.58
Fe_2O_3	1.77	2.23	1.51	1.01	.54	.77	3.20	.16
FeO	.26	3.51	.26	.16	.33	.11	2.02	.58
MgO	.16	2.60	.21	.33	.56	.18	2.30	2.79
CaO	.09	4.27	.12	.18	.16	None.	6.06	6.25
Na_2O	.24	4.08	.24	None.	.12	.06	2.76	.27
K_2O	6.31	3.17	5.11	6.03	3.20	1.68	2.81	2.46

An inspection of these analyses shows a marked variation in the potassium content, and a sampling of the tailings would be required to determine the average composition.

Since 1904, 3,342,000 tons of ore has been mined in the district, and as most of this was milled there is a large accumulation of tailings.

OTHER DISTRICTS.

There are numerous other districts in which the ores and associated rocks contain notable amounts of potassium, among which may be mentioned the deposits of the Black Mountains, Ariz.,[1] which contain potassium in the mineral adularia (orthoclase feldspar).

[1] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: U. S. Geol. Survey Bull. 397, p. 48, 1909.

Schrader [1] has described deposits in the Jarbidge district, Nev., which contain an unusual amount of potassium. A general sample of the ore from one mine gave 11.84 per cent of potash (K_2O), and it is estimated that some of the ore contains as much as 15 per cent.

Lindgren [2] has described deposits in Idaho, specimens of the ore from which contained 15.12 per cent and 14.95 per cent of potash (K_2O).

There are doubtless numerous other deposits in the West that contain potassium in noteworthy amounts.

NOTE ON MUSCOVITE.

By George Steiger.

In connection with the general subject of the constitution of silicates, some experimental work was done on muscovite in the chemical laboratory of the United States Geological Survey several years ago, and the results may possibly have some bearing upon the commercial extraction of potash from that mineral.

Clarke [3] states that from the composition of muscovite a splitting up into water, leucite, and sillimanite may be inferred according to the equation—

$$Al_3KH_2Si_3O_{12} = AlKSi_2O_6 + Al_2SiO_5 + H_2O$$

Doelter [4] identified large quantities of leucite and a substance resembling nephelite in the fusion product of muscovite. As shown by Clarke and Steiger,[5] if leucite is heated in a sealed tube with ammonium chloride the potassium is wholly converted into the soluble chloride and may be easily separated by treating with water.

A brief outline of the results of the experiments on muscovite follows and is published in advance of the complete report on the investigation, in the belief that the facts determined have a technologic bearing and may possibly be used as a starting point in the development of a commercial process for the utilization of muscovite-bearing rocks.

Finely ground muscovite [6] was intimately mixed with ammonium chloride in a mortar, and the material was then put into glass tubes, sealed, and heated to 350° C. in a bomb furnace. The tubes were next opened and their contents were leached with hot water and

[1] Schrader, F. C., A reconnaissance of the Jarbidge, Contact, and Elk Mountain mining districts, Elko County, Nev.: U. S. Geol. Survey Bull. 497, p. 53, 1912.

[2] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 167, 1900.

[3] Clarke, F. W., The data of geochemistry, 2d ed.: U. S. Geol. Survey Bull. 491, p. 376, 1911.

[4] Doelter, C., Neues Jahrb., 1897, Bd. 1, p. 1.

[5] Clarke, F. W., and Steiger, George, U. S. Geol. Survey Bull. 207, p. 16, 1902.

[6] Most of the slime tailings from the copper mill pass through a 200-mesh screen.

washed until the wash water gave no test for chlorine. The results are stated below.

Results of heating muscovite with ammonium chloride.

		1	2	3
Leach water	K_2O+Na_2O	10.38	10.53	2.70
Residue from leach water:				
Soluble in HCl	Al_2O_3	4.79	3.55	8.19
	K_2O	.60	.33	1.08
	$(NH_4)_2O$	3.78	3.50	1.00
Soluble in Na_2CO_3 after HCl	SiO_2	10.34	Undet.	Undet.

1, 2, Ammonium residues from fused muscovite; 3, ammonium residue from unfused muscovite. K_2O in leach water given in calculated percentages of raw muscovite; other determinations in calculated percentages of dried residues.

The muscovite used contained 9.55 per cent of K_2O and 1.20 per cent of Na_2O, a total of 10.75 per cent. Of this amount practically the whole was found in the leach water, showing that by first fusing the muscovite and then treating it with ammonium chloride its potassium was entirely converted into the soluble form. The results given in column 3 show that more than 25 per cent of the potassium present may be converted into the soluble form by the treatment with ammonium chloride alone.

Some experiments were also made to determine to what extent potassium might be extracted from muscovite by treatment with hydrochloric acid. The results stated below show that by a very superficial treatment with hydrochloric acid approximately one-third of the potassium may be extracted.

	Per cent K_2O.
Boiled 5 minutes with 1-1 HCl	3.36
Boiled 5 minutes with 1-10 HCl	2.94
Boiled 30 minutes with 1-1 HCl	4.24
Boiled 30 minutes with 1-50 HCl	3.21

As shown in Bulletin 207, the treatment of a leucite rock[1] with ammonium chloride without the preliminary fusion will convert the potassium of the leucite entirely into the soluble form. If an open vessel is used, however, instead of the sealed tube, and the heating is continued too long the action is reversed. The soluble potassium salt which is formed at first will react with the insoluble ammonium compound, and the potassium itself will become insoluble.

[1] An estimate of the quantity of leucite-bearing rock available in the Leucite Hills, Wyoming (U. S. Geol. Survey Bull. 512, p. 35, 1912) gives nearly 2,000,000,000 tons, containing an average of 10 per cent of potash.

RECENT ALUNITE DEVELOPMENTS NEAR MARYSVALE AND BEAVER, UTAH.

By G. F. Loughlin.

INTRODUCTION.

In 1910 certain deposits of "pink spar" about 7 miles southwest of Marysvale, Utah, were recognized as alunite, the double sulphate of aluminum and potassium. Since January, 1911, many alunite locations have been made in this region. Prospecting and development have been essentially continuous in the hope of developing a commercial source of potash salts, and this hope now appears to have been realized. The greatest amount of development work has been done on the Gillan-Custer group of claims, operated by the Mineral Products Corporation, of Marysvale.

A demonstration of the feasibility of extracting potassium sulphate from alunite, by W. T. Schaller, was published by the United States Geological Survey, on December 18, 1911.[1] This process has been worked out on a commercial scale by the Mineral Products Corporation, which recently erected the first mill for the treatment of alunite in the country and made its first production of potassium sulphate on October 7, 1915. On October 20 a carload of 28 tons of potassium sulphate, reported to be 93 per cent pure, was shipped in cotton bags to the Armour Fertilizer Works, at Jacksonville, Fla.[2] It is reported that at least one other company has plans for the erection of a mill.

The first discoveries on the Gillan-Custer group of claims were visited by C. W. Hayes, then chief geologist of the United States Geological Survey, in March, 1911, and were later examined by B. S. Butler and H. S. Gale, the results of whose work, including a general geologic reconnaissance of the Marysvale region, were published in 1912.[3] Public interest in the more recent developments prompted a second examination of the region in 1914, and this field work forms

[1] U. S. Geol. Survey Press Bull. 30, 1911.

[2] Telegram from Charles H. MacDowell, president Armour Fertilizer Works: Manufacturers Record, Oct. 21, 1915, p. 52. A private letter from Gascoyne & Co., Baltimore, Md., dated Nov. 10, 1915, reports that analysis of potash of this shipment showed 95.39 per cent of potassium sulphate.

[3] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, January, 1912. See also U. S. Geol. Survey Press Bull. 30, Dec. 18, 1911.

the basis of the present report. In October, 1915, during the first days of operation of the Mineral Products Corporation, the region was visited by H. S. Gale and V. C. Heikes, of the United States Geological Survey. Mr. Gale's description of properties either inaccessible in 1914 or developed since then and Mr. Heikes's description of the mill are incorporated in the following pages.

The known alunite deposits in Utah are in Piute County, on the east side of the Tushar Mountains, and in Beaver County, on the west side, but only those in Piute County are at present of commercial importance. The deposits of Piute County are from 7 to 8 miles

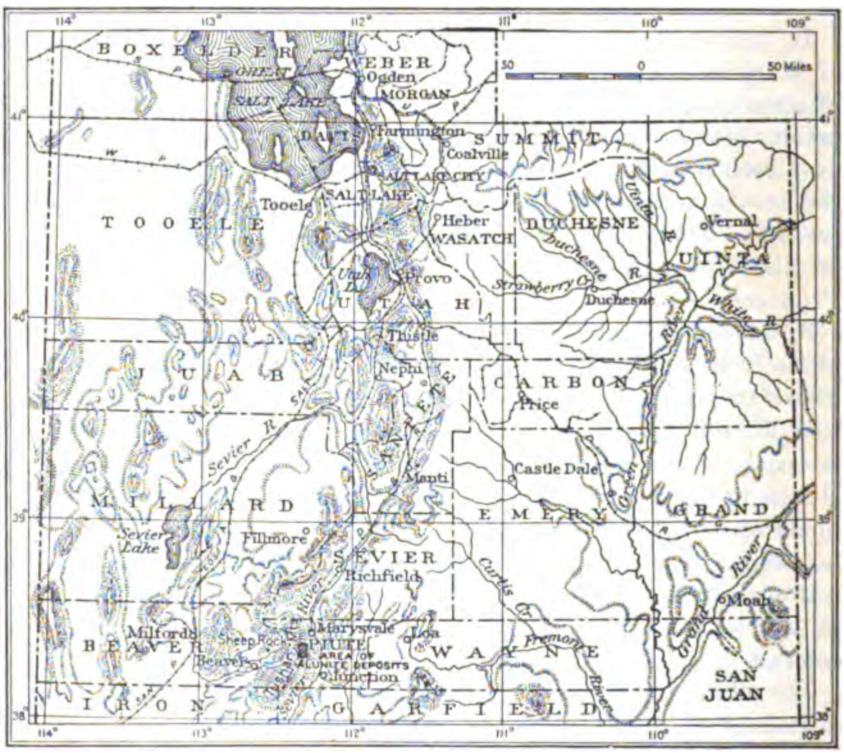

FIGURE 13.—Index map showing location of alunite deposits near Marysvale and Beaver, Utah.

southwest of Marysvale, in the Ohio and Mount Baldy mining districts, and those of Beaver County are about 10 miles northeast of Beaver, in the Newton mining district. (See fig. 13.)

Marysvale, at the terminus of the Marysvale branch of the Denver & Rio Grande Railroad, is about 120 miles south of the main line of the same system. Beaver is 40 miles southwest of Marysvale and about 35 miles east of Milford, on the San Pedro, Los Angeles & Salt Lake Railroad.

GEOLOGY OF THE TUSHAR MOUNTAINS.[1]

The Tushar Mountains form part of a long north-south range between the valley of Sevier River on the east and a broad desert valley on the west. The floor of Sevier Valley near Marysvale has an elevation of about 5,600 feet and that of Beaver Creek at Milford about 5,450 feet. From these depressions the mountains rise boldly, the highest summits of the range, situated northwest of Marysvale, attaining elevations of nearly 13,000 feet.

The range is composed of both sedimentary and igneous rocks. It is outlined by north-south faults and is thus like the ranges of the Great Basin province to the west. However, the bedded rocks, including sediments and volcanic flows, are not greatly tilted, and in this respect the structure is like that of the plateau province to the east.

The sedimentary rocks exposed along the mountain front west and southwest of Marysvale comprise limestones and quartzites having an aggregate thickness of perhaps 2,000 feet. These formations are regarded as of Jurassic age.

Resting on the eroded surface of the sedimentary rocks are effusive volcanic rocks comprising lava flows and tuffs. In general the lower part of the volcanic series is composed of dacite, but chemical investigation may show that some andesite also is present.

Above the dacite, forming the highest part of the range and, toward the north, extending far down the slopes, is a series of light-colored rhyolite flows and tuffs, locally called shale. Southeast of Beaver there are basalt flows that are younger than the rhyolite. The alunite veins of the region, so far as observed, are in that part of the volcanic series which lies below the rhyolite flows.

Of later origin than the rhyolite and tuff series are intrusive rocks which, though of diverse composition, are all related to quartz monzonite. These rocks occupy relatively small areas, but the mineral veins of the region are later than them and are undoubtedly related to them genetically.

The Tushar Range is delimited on the east and west by prominent faults, and within the range there has also been faulting and fissuring, which have affected all the rocks except possibly the basalts. In the main these faults within the mountains show northerly to northwesterly trends, but there are a few cross breaks.

The mineral deposits, consisting mostly of veins but including some irregular replacement bodies, conform in occurrence with the faulting and fissuring, and thus most of them show northerly to northwesterly trends. These deposits comprise two distinct mineralogic types, one containing no alunite and the other composed almost

[1] This description is summarized from U. S. Geol. Survey Bull. 511, already cited.

entirely of alunite or of alunite and quartz. In general the alunite deposits do not contain sulphides or related minerals in conspicuous amount, whereas the other veins do, and some of them have been worked for metals, principally silver and gold. Only the alunite deposits were examined by the writer. Those southwest of Marysvale are distinct though irregular veins, whose formation was accompanied by a minor amount of replacement, but the deposit at Sheep Rock, northeast of Beaver, is an irregular replacement body.

ALUNITE DEPOSITS SOUTHWEST OF MARYSVALE.

LOCATION AND EXTENT.

The best-known alunite deposits southwest of Marysvale are in secs. 8, 16, and 17, T. 28 S., R. 4 W. They lie in three roughly

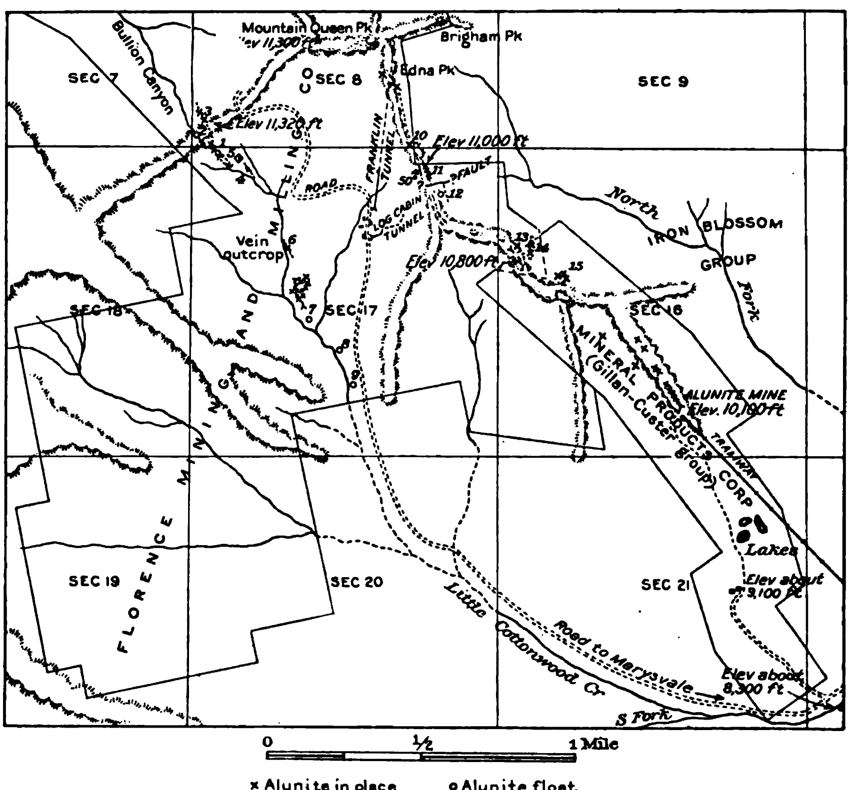

FIGURE 14.—Map showing location of prospects in the principal group of alunite deposits near Marysvale, Utah. Numbers refer to descriptions in text.

parallel zones of northerly to northwesterly trend, the eastern and middle zones on or near the crests of ridges near the headwaters of Little Cottonwood Creek and its North Fork, the western zone close

to the bed on the main stream. (See fig. 14.) The prospects along the main stream can be reached directly by a circuitous wagon road, with an ascent of about 5,000 feet. Prospects east of the creek (main fork) can be connected by short inclined tramways with this wagon road, or by long tramways, like that of the Mineral Products Corporation, extending to roads nearer Marysvale.

Other deposits, only little prospected in 1914, lie east and south of those just mentioned. The prospects on the Lost Horse and Mohawk group of claims are about 2 miles farther from Marysvale than those on the three main zones, and are reached by trail from the Little Cottonwood Canyon road. Still others have been reported to lie south of the divide between Little Cottonwood and Tenmile canyons.

CHARACTER.

GENERAL FEATURES.

All the deposits thus far found are doubtless veins cutting porphyry (altered dacite), though in only a few exposures have their true thicknesses and exact trends been determined. The alignment of prospect pits and trenches and the distribution of float, however, indicate for the most part trends of N. 20°–40° W., though at a few openings the trend is nearly due north. The dips of the different veins are for the most part 50°–70° W., but vertical dips have been noted at a few places and a steep easterly dip was recorded at one obscure exposure. None of the veins have been opened continuously along their strike, but the alignment of openings indicates probable lengths of 500 to 800 feet for continuous veins and of 1,500 to 5,000 feet for vein-zones. The widths of the veins or vein zones are considerable, but the prospect trenches on all but the Custer vein did not, as a rule, afford a satisfactory estimate of the width or thickness. The Custer vein contains an average thickness of about 10 feet of high-grade alunite, on each side of which smaller veins or bands of alunite alternate with similar thicknesses of quartz or highly silicified porphyry.

The best exposure in the western zone is on the L. & N. No. 4 claim and shows an exposed thickness of 26 feet, of which 20½ feet is high-grade alunite and 5½ feet quartz. Other openings show thicknesses of 8 to 20 feet. The veins are distinctly banded, bands of nearly pure alunite alternating with bands of quartz. The alunite portions themselves are for the most part banded by parallel to concentric markings similar to those in travertine, or "onyx marble," and characteristic of open fissure fillings, but there is also evidence of replacement on a minor scale. The general distribution of the veins is indicated on the surface by elongate to irregular areas of silicifica-

tion, many of which appear to have determined the positions of ridges and prominent peaks through their superior resistance to erosion.

Three varieties of alunite have been noted in the veins—coarsely crystalline, fine grained to dense, and laminated. The coarsely crystalline variety is by far the most common. It is pink to reddish, and forms large masses of columnar to platy crystals as well as small veinlets that cut the other two varieties. It is practically pure but contains minute quantities of pyrite or limonite and silica (chalcedony and opal). It is most readily recognized in the field by these properties, together with its high specific gravity (about 2.82[1]), which is distinctly higher than that of calcite (2.71), the only mineral in the region that is likely to resemble it in crystalline form.

The fine-grained variety is pink to white and resembles porcelain where hard and chalk where softened by weathering. Under the microscope some specimens are seen to consist almost entirely of minute crystals of alunite with only an apparently negligible amount of pyrite, silica, and kaolin; but in other specimens these impurities are more conspicuous. The fine-grained variety may resemble kaolin, or miner's "talc," especially if enough kaolin is present to yield its characteristic odor; but the fine-grained alunite, like the coarse-grained variety, may be recognized by its high specific gravity.

The laminated or shaly variety differs from the fine-grained variety only in its structure, which is evidently due to shearing along the plane of the vein. Such a structure could have been developed in either of the other varieties.

DETAILED DESCRIPTIONS.

The following detailed descriptions of the alunite, associated quartz, and altered wall rock are given for the benefit of those especially interested in the mineralogy and genesis of the veins:

ALUNITE.

In the coarsely crystalline variety of alunite the crystals have a tubular form and occur in diverging columnar aggregates crossed by parallel lines or bands. In some places the larger crystals extend across these bands; in others the bands mark either interruptions or possibly sealed fractures. The diverging character of the crystal aggregates is even more noticeable under the microscope than in hand specimens. The rhombohedral faces of the crystals are not usually well developed, but in many places an open cavity between two bands shows well-developed rhombohedral faces, which, however, have commonly been etched by later solution. What in the hand specimen appear to be crystals are seen under the microscope to be composed of numerous smaller crystals diverging from a central axis, forming a striking plumose structure.

[1] This figure is near the average of several determinations of Marysvale alunite by W. T. Schaller, of the United States Geological Survey. According to Dana's Textbook of mineralogy (edition of 1900, p. 587) the specific gravity is 2.58 to 2.75.

The lines marking the separation of the bands forming the vein are seen under the microscope to consist of narrow bands of finely crystalline material of various orientation. Where the larger crystals or aggregates cross these lines without change in orientation, they give the impression that the fine material has been deposited in fractures breaking across the crystals. It is more probable, however, that a slight change in conditions interrupted deposition or altered its rate and caused the deposition of several minute unoriented crystals instead of the large crystals, after which a return of the original conditions permitted the largest crystals to continue their growth, while crystallization in part began at new centers. Some of the lines are due to a change in color without change in crystal character and are to be attributed to slight changes in the composition of the depositing solution, such as the presence or absence of a trace of iron oxide. Parallel wavy or concentric bands of this type are very common in cavern deposits such as stalactites, stalagmites, and crusts lining cave and fissure walls, and their presence in the alunite veins is regarded as proof that this variety of alunite was deposited as an open-fissure filling. Cavities between banded aggregates pointed toward each other mark places where the openings were not entirely filled.

The lines that mark the boundaries between crystal aggregates growing away from each other require a different explanation. There must have been a surface or narrow strip of material on which the aggregates began to grow but which is no longer present. It is suggested, from evidence presented in a subsequent paragraph, that there was formerly present a narrow strip or sheet of the fine-grained alunite, which has since disappeared by recrystallization into the coarsely crystalline variety.

As seen under a low power of the microscope the coarsely crystalline variety appears to be almost pure, but when it is studied under high power numerous yellow globular masses are revealed, most abundantly between the crystals or along minute fractures. These masses are probably limonite. Some small spaces and also certain lines of zonal growth across the crystals are filled or marked by cloudy material, some of which looks like kaolin, some like minute cubes of pyrite, and some like minute bubble inclusions, while much of it is in specks too small to warrant even a suggestion as to their character. A few minute crystals of undoubted pyrite are present in the alunite. It also includes numerous irregular microscopic masses of an undetermined mineral that appears to be isotropic and has an index of refraction below that of alunite. Some of these masses may be opal; others of similar appearance in ordinary light prove between cross nicols to be doubly refracting aggregates with a birefringence like that of quartz.

In one specimen from the mouth of the tunnel on the L. & N. No. 4 claim of the Florence Mining & Milling Co. the casts of several crystals of a tetragonal or orthorhombic mineral are present in coarsely crystalline alunite. The casts are as much as half an inch in length, about a millimeter in width, and square to diamond shaped in cross section. They are fringed by rows of alunite crystals growing normal to the edges of the casts and are partly filled with a brown powder, shown under the microscope to consist of an indeterminate amorphous material stained with brown iron oxide and containing scattered crystals of alunite. The crystal outline and mineral association suggest that the original mineral may have been diaspore.

The fine-grained, porcelain-like variety is seen under the microscope to be a granular mass composed of irregular crystals of alunite. No distinct grains of quartz were recognized in the few thin sections studied, although the only analysis of this variety shows the presence of 5.28 per cent silica. In some

thin sections distinct though minute grains of pyrite, partly or wholly oxidized to limonite, are thinly scattered through the alunite mass. The fine-grained variety in part forms thin bands between uniformly oriented bands of the coarsely crystalline variety but for the most part is cut by parallel and linked veinlets of the coarsely crystalline alunite.

Where the fine-grained material alternates with uniformly oriented bands of the coarse-grained material it probably represents changes in conditions of crystallization in an open fissure; where it is cut by veinlets of the coarse-grained alunite it was undoubtedly the first to form, and the veinlets were probably in part derived from it. Both megascopic and microscopic study of the látter phase show that the coarse crystals in these veinlets have formed in part, if not wholly, by recrystallization of the fine-grained mass, single large crystals growing at the expense of many small ones. Lenticular patches of the fine-grained type inclosed between coarse-grained veinlets diminish to mere lines between bands of crystals, and large crystals project into the fine-grained aggregates or may even inclose a few fine crystals just within their boundaries. So far as microscopic data are concerned, this process is one of simple recrystallization. The minute pyrite grains in the fine variety are no more than enough to account for the dusty patches and zonal groups, some of which are pyrite or limonite, in the coarse crystals. Silica is too scarce in either variety, so far as seen under the microscope, to be of much significance in this connection. The small amount noted in the coarsely crystalline variety was formed either at the same time as the alunite crystals or slightly later and may represent a small amount of submicroscopic silica in the fine-grained type. Further collection and study of impure phases of the fine-grained type are needed to throw definite light on this question.

No distinct transition between the fine-grained alunite and the silicified and alunitized wall rock was noted in the exposures of rock in place. Coarsely crystalline alunite was found in direct contact with silicified rock, both at the walls and within the veins. Loose fragments, however, along some of the prospect trenches consist of rather highly alunitized material which still preserves more or less distinctly the porphyritic texture of the local wall rock. This evidence suggests that there may be a transition between practically pure fine-grained alunite and the silicified and alunitized wall rock.

The shaly or schistose variety was noted only at exposures in and just northwest of the Gillan-Custer claims. It is microcrystalline and contains numerous slickensided partings, which indicate a strong shearing movement along the vein. It consists, like the other varieties, of almost pure alunite in which there are a few minute crystals of pyrite (or limonite). It also contains veinlets and small vugs of coarsely crystalline alunite, so arranged as to leave little doubt that they have resulted from local recrystallization of the sheared alunite where small fractures made conditions favorable.

QUARTZ.

The quartz bands that alternate with those of alunite have been noted in the western vein zone (see fig. 14) and in the Custer or eastern zone. Further developments will doubtless prove their existence in the middle zone as well. The bands consist of dense or microcrystalline quartz with a little pyrite in fine grains. In places they show a faint trace of porphyritic texture, suggesting replacement of porphyry rather than open-fissure filling. In the western zone, as shown on page 249, the quartz bands occur at irregular intervals throughout the width of the vein; in the Custer or eastern zone they alternate with smaller veins of alunite on each side of the main alunite body. The

contrast in character between this dense form of quartz, or highly silicified porphyry, and the pure crystalline alunite is striking and not satisfactorily explained from the evidence at hand.

WALL ROCK.

Alteration of the wall rock along the alunite veins is pronounced and extends for many feet on each side. The altered rock, dacite porphyry, is white to pale pinkish where not stained by iron oxides and of dull or chalky luster. The original porphyritic texture is distinctly preserved and is especially prominent on iron-stained surfaces, where the iron oxides have colored the groundmass but not the phenocrysts. The principal minerals present are quartz, alunite, and pyrite, with small amounts of limonite, kaolin, apatite, and zircon.

The alunite, as seen in thin section, occurs principally as interlocking aggregates of lath-shaped crystals, either pure or accompanied by some secondary quartz, replacing feldspar phenocrysts. These, as suggested by their outlines and by the character of feldspar phenocrysts in this type of rock in general, were probably mostly if not all of plagioclase, the soda-lime feldspar. Alunite also forms smaller aggregates and single crystals scattered through the groundmass but hardly in great enough amount to represent all the original feldspathic material of the groundmass.

The quartz occurs as original phenocrysts which have been only slightly, if at all, affected during the alteration process. The only suggestions of their alteration are where alunite laths penetrate their edges and where an alunite lath is found wholly within a quartz phenocryst. The penetrating alunite laths may merely represent small original embayments of the phenocryst by the groundmass, but the presence of an alunite lath within a quartz phenocryst suggests that the quartz may have been to a slight extent replaceable by the alunite. Quartz in very minute granular aggregates now forms the greater part of the groundmass and must have replaced at least a part of the original material, as no feldspar of any kind could be recognized. The groundmass is clouded by a very fine dust, which may be in part kaolin but is probably for the most part minute grains of pyrite and limonite. A few small veinlets and irregular aggregates of secondary quartz are present, and some of them contain a few laths of alunite which evidently grew at the same time as the quartz.

The presence in the same thin section of a parallel growth of secondary quartz and alunite and of primary quartz phenocrysts penetrated by alunite appears contradictory, but the material observed is so scant and in grains so small that no great significance can be attached to it.

The pyrite forms evenly scattered grains as much as 1 millimeter or more in diameter and constitutes 4 or 5 per cent of the rock. It is equally abundant in association with the alunite aggregates and with the secondary quartz in the groundmass, and it crystallized at the same time as these minerals. The prominence of pyrite in the wall rock is in marked contrast to its obscurity in the alunite veins. The absence of the black silicates, augite, hornblende, and biotite, in the altered wall rock is also noteworthy, and it may be that the iron originally present in these minerals is now largely contained in the pyrite.

Kaolin is present in varying though small amounts, probably as minute specks closely associated with alunite in the replaced feldspar phenocrysts. Its presence may be detected by the rather weak but characteristic odor of the moistened specimen. Limonite is present as brown surface stains and varies in amount with the degree of oxidation of the pyrite. Small apatite and zircon crystals, unaffected by the alteration process, are rather abundant in some thin sections.

It is clear from these data that the magnesia, lime, and soda originally in the wall rock were removed, while silica, the sulphide and sulphate radicles, and water were introduced. Until analyses of the fresh and altered rock can be compared it can not be determined whether aluminum, iron, or potassium were added or remained in practically their original amounts. Furthermore, although the alunite occurs mostly as a replacement of soda-lime feldspar, it is not known whether the alunite in the rock is the pure potassium variety, like that in the veins, or the sodic variety. In either case, some potassium was introduced into the feldspar phenocrysts, but the amount originally in the groundmass would doubtless have been enough to account for the potassium in sodic alunite, whereas some additional supply may have been necessary to account for potash alunite, especially where the alunitization of the porphyry is most pronounced.

A preliminary examination of the wall rock of other than alunite veins in the region has not disclosed the presence of alunite, though a more thorough study may do so. It may be noted, however, that metallic minerals are reported from prospects, now inaccessible, around Edna Peak (locally called Edna Geyser), where alunitization of the rock is pronounced.

CHEMICAL COMPOSITION.

The following analyses of Marysvale alunite, which are all at present available, show the character of the coarsely crystalline and dense white varieties:

Analyses of alunite from Marysvale region, Utah.

Crude alunite from Custer group.[a]

	1	2	3
Alumina (Al_2O_3)	37.18	34.40	37.0
Ferric oxide (Fe_2O_3)	Trace.	Trace.	
Sulphuric anhydride (SO_3)	38.34	36.54	38.6
Phosphoric anhydride (P_2O_5)	.58	.50	
Potash (K_2O)	10.46	9.71	11.4
Soda (Na_2O)	.33	.56	
Water above 105° C. (H_2O+)	12.90	13.08	13.0
Water below 105° C. (H_2O-)	.09	.11	
Silica (SiO_2)	.22	5.28	
	100.10	100.18	100.0

[a] Copied from U. S. Geol. Survey Bull. 511, p. 8.

1. Selected specimen of clear pink, subtransparent, coarsely granular crystalline alunite. Supposedly best material. W. T. Schaller, analyst.
2. Selected specimen of a light-pink, very finely granular rock, of almost porcelain-like conchoidal fracture and no distinct structure. W. T. Schaller, analyst.
3. Theoretical composition according to Dana, Textbook of mineralogy, 1900 edition, p. 537.

Coarsely crystalline alunite from Florence Mining & Milling Co.'s claims.

	4	5
Loss on ignition	42.8	42.1
Insoluble residue (alumina with perhaps a little silica)	39.3	37.6
Potassium sulphate (K_2SO_4)	16.8	18.5
Equivalent potash (K_2O)	9.1	10.0

4. 1,000-pound sample from Sunshine Fraction claim.
5. 1,000-pound sample from North Fork claim.

Calcined alunite.

[Said to represent the average of the coarsely crystalline alunite used in analyses 4 and 5. Determined by fusion with sodium carbonate.]

	4a	5a
Silica (SiO_2)	0.03	0.72
Alumina (Al_2O_3)	61.1	61.1
Ferric oxide (Fe_2O_3)	1.6	1.1
Sulphuric anhydride (SO_3)	19.0	18.1
Potassa (K_2O)	17.2	18.6
Lime (CaO)	None.	None.
Magnesia (MgO)	.29	.31
	99.22	99.93

[The same material determined by leaching.]

	4b	5b
Insoluble residue	61.8	62.2
Potassium sulphate (K_2SO_4)	32.6	32.0
Aluminum sulphate ($Al_2(SO_4)_3$)	4.4	5.0
	98.8	99.2

4 and 5, 4a and 5a, 4b and 5b made by Solvay Process Co. for Florence Mining & Milling Co.

Comparison of analyses 4 and 5 with No. 1 shows that the coarsely crystalline alunite in the prospects on the Sunshine Fraction and North Fork claims (Nos. 11 and 14, respectively, in fig. 14), south and southeast of Edna Peak, is practically identical in composition with that in the Gillan-Custer prospects and is almost entirely free from impurities. Microscopic examinations of coarsely crystalline alunite from prospects west of Edna Peak indicate a similar degree of purity. Material of this quality is fit for the extraction of both potash salts and alumina, as well as for the manufacture of alum and for use as fertilizer.

Analysis 2 shows that the fine-grained variety contains a considerable amount (5.28 per cent) of silica. More analyses of material of this type would doubtless show some variation in silica content. An amount of silica as great as 5 per cent is sufficient to increase considerably the cost of extraction of alumina in a form sufficiently pure to be used in the manufacture of metallic aluminum—so much, perhaps, as to render it unprofitable—but it does not unfit the material for the manufacture of alum or for use as fertilizer.

Recalculation of analysis 1 shows it to contain 92.74 per cent of the potash alunite molecule ($K_2O.3Al_2O_3.4SO_3.6H_2O$). The amount of soda present is equivalent to 3.98 per cent of soda alunite, but the total water in excess of that required by the potash alunite is not enough to satisfy this amount. Alumina in excess of the amount required by the total alunite amounts to 1.43 per cent, and the corresponding excess of the sulphate radicle is 0.88 per cent. Some of this

alumina may be combined with the sulphate, some with the phosphate radicle, and some with silica, but nearly or quite all such natural compounds contain water, which according to the analysis is not present. The silica, furthermore, is believed to represent the small amounts of quartz and opal noted under the microscope.

Recalculation of analysis 2 shows it to contain 85.28 per cent of the potash alunite molecule and 5.57 per cent of the soda alunite molecule, with excesses of 0.71 per cent of alumina, 1.36 per cent of the sulphate radicle, and 0.04 per cent of total water. The deficiency of water again precludes the expression of these excesses as natural minerals. The predominance of excess sulphate radicle in analysis 2 is in contrast to the predominance of excess alumina in analysis 1, and the discrepancy also indicates that these materials are not present as definite compounds but are probably occluded in the alunite. The silica in analysis 2 is greatly in excess of that required to form kaolin with the excess alumina and doubtless represents one or more varieties of free silica.

PROSPECTS.

PRINCIPAL GROUPS.

The principal groups of alunite prospects lie in three roughly parallel zones of northerly to northwesterly trend. (See fig. 14, p. 240.) The western and middle zones are within the property controlled by the Florence Mining & Milling Co., whose headquarters are at Philadelphia, Pa., but it is reported that some of the claims along the western zone have been relocated in 1915, and their ownership is at present in doubt. The eastern zone has its north end within the southeast corner of the same property but lies for the most part within the Gillan-Custer group of claims, which belong to the Mineral Products Co., of Chicago, Ill., and is operated by the Mineral Products Corporation, of Marysvale, Utah.

WESTERN ZONE.

The western zone trends northwestward and roughly parallels the north headwater branch of Little Cottonwood Creek. Alunite has been exposed at a number of places in this zone. Near the Little Cottonwood Canyon and Bullion Canyon divide, on the L. & N. No. 4 claim, a vein striking N. 40° W. and dipping about 40° W. is exposed for a distance of 40 feet along a N. 25° E. trench (No. 1[1]) and for 60 feet along a N. 70° W. tunnel.[2] The tunnel portal and the north end of the trench are at the northeast wall of the vein,

[1] Numbers in parentheses correspond to numbers in figure 14 (p. 240).

[2] It is reported that since the writer's visit this tunnel has been extended for 100 feet along the vein and is in alunite all the way. (Oral communication by W. A. Fitzpatrick, Florence Mining & Milling Co.)

but the southwest wall has not been found. The true width at this place is therefore not known but is at least 35 feet, and the corresponding true thickness is at least 25 feet. The following section, made along the trench, shows that the vein contains at this place about 80 per cent of high-grade alunite, the true thickness being 20½ feet of alunite and 5½ feet of quartz.

Section along trench at locality No. 1.

Northeast wall of alunitized and pyritized porphyry.	Feet.
Coarse crystalline alunite	2½
Quartz	2
Coarse crystalline alunite	1
Quartz	3
Coarse crystalline alunite	9½
Quartz	½
Coarse crystalline alunite	7½
	26

The alunite, quartz, and wall rock are typical and need no further description.

At 80 feet northwest of the tunnel portal float of alunitized porphyry and some well-crystallized alunite are exposed in a line of shallow trenches. Farther northwest, on the crest of the divide, alunite fragments are exposed in a small cut (No. 2). These occurrences suggest a forking of the vein or two or three parallel veins. Just north of the crest of the ridge and about 250 feet northeast of the cut last mentioned are two shallow cuts (No. 3), exposing alunite, which appears to be a vein of northwesterly trend, 8 feet wide.

Southeast of the tunnel alunite, mostly in loose fragments, has been exposed in three shallow trenches, the southeasternmost of which (No. 4) lies about 650 feet from the tunnel. An old shaft dump (No. 5) just northeast of the middle trench and 400 feet from the tunnel consists largely of alunitized rock. At none of these places has sufficient work been done to show the direction and width of the vein or its percentage of high-grade alunite. The position of the vein at the tunnel suggests either that the southeasternmost of the three cuts may represent a parallel vein, or that the vein has been offset by faulting.

The next exposure of alunite to the southeast is an outcrop (No. 6) close to the east bank of the creek, 1,500 feet from the cut last mentioned, and in line with the strike of the vein exposed in the tunnel. From 500 to 1,000 feet farther south alunite and alunitized rock have been exposed in a group of small cuts and in two short tunnels (No. 7). Alunite float has been reported along the east side of the creek for the next 1,500 feet southeastward (Nos. 8 and 9), but little or no development work had been done on it up to the fall of 1914.

MIDDLE ZONE.

The middle zone extends along the crest of the ridge which divides the North Fork from Little Cottonwood Creek. Alunite has been traced in this zone from Edna Peak southward to the fork of the ridge but has been prospected thus far only by shallow trenches.

At Edna Peak alunite has been found both on the northwest and southeast slopes. Only one vein, that on the southeast slope of the peak, has been traced, and no work has been done to determine whether the exposure on the northwest slope is a branch of the same vein or is a parallel vein which pinches out toward the south. About 900 feet south of Edna Peak the alunite vein, which strikes N. 15° E. and dips steeply to the east, is shown in a trench (No. 10) to have a width of over 15 feet, but neither wall is exposed. Farther south it is partly exposed in five trenches (No. 11) and has an average dip of about 50° W. The length exposed by the six trenches is about 650 feet; the length from Edna Peak to the southernmost of these trenches is about 1,550 feet. Beyond the southernmost trench the vein appears to have stopped abruptly, but the surface is so thickly covered by loose rock that it is impossible to determine on the surface whether the vein pinches out or is cut off by a fault, as suggested in figure 14. Nearly 400 feet farther south and a little east of the course of the vein a small amount of alunite has been exposed in three shallow trenches (No. 12), but not enough work has been done here to demonstrate the size of the vein. The abundance of alunite float down the slope east of these trenches suggests that the strongest vein at this place has not been uncovered. No further excavations have been made to test the southward extent of this zone. A partial analysis of coarsely crystalline alunite from this vein, on the Sunshine Fraction claim, is given in column 4 of the table on page 246.

EASTERN ZONE.

The eastern zone includes three distinct groups of exposures and probably three or more veins. It has been prospected on the spur southwest of the North Fork of Little Cottonwood Creek, as shown in figure 14. The prospects farthest to the northwest include three pits on the ground of the Florence Mining & Milling Co. The western pit (No. 13) exposes alunite, which is also represented by float on the knob directly to the south. About 200 feet due east of this pit are two shallow trenches (No. 14) mostly in loose fragments of alunite and altered rock but also exposing high-grade material in place. The strike of the vein here is N. 5° E., and the exposed width of high-grade alunite is 15 feet. The strike of the vein proves it to be distinct from the alunite exposed to the west. A partial chemical

analysis of the alunite is given on page 246, column 5, and agrees closely with the other analyses of high-grade alunite.

The remaining exposures in the eastern zone are in the prospects on the property of the Mineral Products Corporation, as shown in figure 14. These were the only developments in 1911, when the data for Survey Bulletin 511 were collected. Since then considerable work has been done on this property. It was idle when visited in 1914 but was examined in October, 1915, by Mr. Gale, whose description of the newer developments is as follows:

The developments on the Gillan-Custer group of claims have been by far the most active. They have included the opening of two principal tunnels in the effort to determine the extent and continuity of the alunite underground and the sinking of numerous shallow pits, shafts, and tunnels with the object of tracing the veins.

The first or lower tunnel on this property was run in below most of the surface croppings of alunite, in an effort to cut the main vein at depth. For a time it seemed as if the vein had been missed, but in the final developments on this level the ore was found and followed for some distance in line with and almost directly under the later development in an upper tunnel. Work at this level was discontinued pending further explorations higher up and nearer the outcrops.

The main tunnel, or present working mine (October, 1915), is about 200 feet higher than the old tunnel. Its portal lies just about over the last extension of the lower tunnel in the line of the vein. It starts on an exposure of massive crystalline alunite which trends about N. 55° W. and dips about 75° S. as measured on the bands of crustification in the vein. At the east side of the portal is siliceous wall rock containing some alunite and stained rusty red so that in appearance it is much like the ore. This tunnel was driven along the ore with the intention of following the footwall side but passed through several breaks or offsets whose origin and relation to the ore were not fully indicated. There was some difficulty in following the ore, but at the time of visit, late in October, 1915, the vein had again been picked up and mining and developments were proceeding in a very satisfactory way. These developments are following directly underneath the line of surface cuts, which expose wide sections of the alunite vein, as described in Bulletin 511.

The underground work done in the exploration and development of this property has disclosed a greater irregularity both in character and continuity of the main veins than was expected from the larger and apparently uniform exposures of crystalline alunite in the surface cuts above. However, it appears that these workings have now opened an ore reserve large enough to insure the operation of the plant for some time and that there is a good prospect of run-

ning into a larger body of high-grade ore beyond, where the surface exposures above are complete and apparently very regular.

It has not been satisfactorily determined whether the irregularities found in the alunite veins are due to faulting or offsets of the veins since their formation, or whether they are an original feature of the deposits. A number of fissures encountered in the present workings are filled with a smooth and very plastic red clay, in places containing angular fragments of the wall rocks. Here and there, however, the original crustification in the main alunite vein appears to pass these clay seams without offset. Some of these clay seams are accompanied by cross veins of crystalline alunite, which are evidently secondary to the main deposit. Owing to obscurity of the vein walls and of the relations at the points where discontinuity of the vein has been found, it can not yet be stated to what these irregularities are due, although doubtless this relation will become clear as mining developments proceed.

The mine as now equipped is capable of supplying 150 to 200 tons of milling ore a day and its capacity can be increased.

OTHER PROSPECTS.

Other indications and prospects thus far reported lie to the east and south of the zone just described. The following notes give the only available information on them at the time of writing:

Iron Blossom group.—The prospects on the Iron Blossom group of claims have not been seen by the writer. There are said to be two occurrences of alunite in place, one on each slope of the North Fork canyon, and one occurrence of alunite float between them close to the bed of the creek. The deposit on the southwest slope of the canyon is near those at the northwest end of the Mineral Products Corporation's ground and evidently belongs to the same vein zone. The other occurrences presumably represent two additional veins, but no definite information regarding them has been obtained.

Gillan's claims.—Alunite has recently been found on Tom Gillan's claims in the foothills 3 miles southwest of Marysvale and three-fourths of a mile east of the Deer Trail mine. According to Mr. Gale, the alunite occurs in veins and bunches associated with a silicified zone in porphyry of the same character as that which forms the country rock about the main alunite deposits higher up in the mountains. Both coarse and fine grained varieties of alunite are present, and the color ranges from white through yellow to pink. Although there are some large blocks of high-grade ore at this locality, the indications of an ore body are not so strongly marked by float as at the main veins of the district. A specimen sent to the writer by Mr. Heikes consists of the fine-grained variety, considerably sheared and accompanied by broken stringers of quartz.

Santa Kruze claims.—A specimen sent by A. Soyka, said to be from the Santa Kruze No. 4 claim, 4,000 feet southeast of the Krotki iron mine, was tested at the Survey laboratory and found to be alunite of good quality. This district doubtless deserves investigation.

Mohawk group.—The Mohawk group is located on the north side of Mill Fork of Little Cottonwood Creek, nearly due south of the prospects on the western vein zone. According to Mr. Gale, new developments on the property include a tunnel and a shaft. The shaft at the time of his visit was 30 feet deep, and in a short crosscut 10 feet to the south some fine-grained white material of uncertain alunite content had been exposed. Since Mr. Gale's visit it has been reported that the shaft had been sunk to a depth of 35 feet and had exposed some massive alunite. The tunnel was being driven N. 14° W. to reach the shaft at a depth of 200 feet below its present bottom.

Lost Horse group.—The Lost Horse group of claims extends along the east side of the crest of the range, south of Mill Fork and the Mohawk group. Alunite has been found in place at two prospects, and float has been followed at several others. These places lie in a nearly north-south zone but are hardly close enough together to be regarded as strong indications of a continuous vein, especially when the northwesterly trends of the vein farther north (see fig. 14) are considered. The alunite in place was found in the summer of 1914 by trenching into a slope where float was abundant, but not enough work was done to determine the width or trend of the vein. The alunite exposed here is a mixture of the coarsely crystalline and fine chalky varieties, the coarse material forming a network of veins through the fine. At the southernmost occurrence of float, on the saddle where the Beaver-Marysvale trail crosses the divide, three or four short trenches have been dug, exposing a considerable amount of the chalky variety, a small part of which is stained reddish or brown. The other float occurrences were not seen. No analyses of alunite samples from this property have been reported.

ORIGIN OF THE DEPOSITS.

So far as origin of the alunite veins is concerned, the evidence presented in the preceding pages practically confirms the statements of Butler and Gale,[1] that the veins were formed, for the most part, in open fissures and, in addition, suggests that a part of the fine-grained alunite may have been formed as a replacement of porphyry. In this respect, as well as in the alteration of the wall rock, the mode of deposition was similar to that of the Sheep Rock deposit, described on

[1] U. S. Geol. Survey Bull. 511, pp. 7, 20, 1912.

pages 258–264, but replacement accounts for practically all the Sheep Rock deposit instead of a part of it. Regarding the source of the alunite-forming solutions, no evidence has been found at variance with the hypothesis of Butler,[1] which is briefly as follows:

During and just subsequent to the consolidation of the intrusive masses all the rocks in the region, both sedimentary and igneous, were fissured. Along these fissures ascended heated solutions believed to have been derived from the intrusive magma. Within the intrusive mass they were highly heated, probably under considerable pressure, and deposited minerals characteristic of this condition. As they passed into the cooler overlying rocks both temperature and pressure were reduced, and the valuable metalliferous veins of the region were deposited. These veins were formed in two stages, the earlier one characterized by carbonate gangue minerals and the later by quartz and adularia. The adularia is of special interest, as it is a pure potassium-aluminum silicate and indicates a certain concentration of these elements during the later stages of vein deposition.

The alunite veins are thought to represent a still later stage of deposition, characterized by a much higher concentration of potassium and aluminum in the form of sulphate. Structural evidence indicating this relation of the alunite to the metalliferous veins is not yet complete. The relation is, however, suggested by the mode of occurrence of alunite in other regions, where general conditions indicate that the mineral was deposited at shallow depth and at moderate to low temperature. The relative rarity of alunite deposits compared with quartz-adularia veins in this country and abroad may be due to the fact that they are formed near the surface and consequently have in only a few places been preserved.

According to this interpretation, it is to be expected that in places alunite veins will be found superimposed on quartz-adularia veins. It might be supposed that the quartz bands which alternate with alunite bands in several exposures represent the quartz-adularia stage and that the alunite is a later deposit introduced after the quartz vein had been reopened by longitudinal fracturing. Such may prove to be the relation in some deposits, but no quartz bands in the veins have been found with the characteristic hackly structure of the quartz-adularia veins, and microscopic study of the wall rock shows simultaneous deposition of quartz, alunite, and pyrite. It is more probable, therefore, that the quartz bands were formed during the same stage of deposition as the alunite, as in the Sheep Rock deposit described on page 262.

Where alteration along the quartz-adularia veins was most intense potassium and aluminum were nearly or quite all removed from the

[1] U. S. Geol. Survey Bull. 511, pp. 21, 38, 1912.

wall rock. In the wall rock of the alunite veins, however, alunite appears to be sufficiently abundant to account for all the potassium of the original rock, and it is therefore certain that the rock immediately adjacent to the alunite veins did not supply the potassium to them by lateral secretion. In fact, where the wall rock has been replaced by the fine-grained alunite there must have been a considerable addition of potassium to the amount already present. It is possible, however, that at least a part of the potassium and aluminum content of the vein was derived from the wall rock at greater depth, where conditions were favorable to the leaching of these elements, and that the enriched solutions, rising into cooler zones, redeposited them in the form of alunite. This interpretation implies that the alunite bodies are deposits of relatively shallow type and may give out in depth or merge into a different type of vein. The fact that, although quartz-adularia veins are of common occurrence in the West, no important alunite deposits have been found associated with them except near Marysvale necessarily leaves this idea as a suggestion rather than a conclusion.

PERSISTENCE IN DEPTH.

As already stated, the characteristic features of alunite deposits in several parts of the world[1] indicate deposition at shallow depths. Recent developments at Marysvale on all but the Gillan-Custer group of claims have been merely superficial, and the deepest workings on that property are only about 260 feet below the lowest outcrops of alunite. The cautious attitude taken by Butler and Gale regarding the persistence of the veins in depth should therefore be maintained.

The foreign deposits that compare most closely in character with the alunite veins of Marysvale are those at Tolfa, Italy. The largest of these deposits, the Providenza vein, has been worked to a depth of more than 300 feet, where it becomes increasingly pyritic, and it ends within the next 60 feet. The downward continuation of the vein zone is marked by pyritic wall rock (trachyte). That in general a greater vertical range than that of the Tolfa deposits can be expected in the alunite veins of the Marysvale region is suggested by the observed distribution of outcrops with reference to the rugged topography. In the eastern zone near Marysvale the highest outcrops according to Gale's observations[2] are at least 1,000 feet above the lowest; in the middle zone the observed vertical distribution, according to surveys for the Florence Mining & Milling Co., is about 900 feet; in the western zone, according to the same authority, it is

[1] Descriptions of these deposits are reviewed by Butler and Gale (U. S. Geol. Survey Bull. 511, pp. 38–58, 1912).

[2] Op. cit., pl. 3.

over 700 feet, and the distribution of float indicates that it may be considerably more. There is no apparent reason why the actual range in depth should not equal or considerably exceed these amounts. It should be borne in mind, however, that the alunite deposits, like many metalliferous deposits, may occur in shoots with a distinct pitch, and that their lowest parts may happen to be along a line roughly parallel to the present surface slope. In this case the shoots in the higher parts of the veins may possibly end downward at levels higher than those of the present lower outcrops.

SUGGESTIONS REGARDING DEVELOPMENT.

Because of the existing uncertainty in regard to the vertical range of the deposits, the safest method of prospecting seems to be the driving of tunnels along the strike of the vein at various levels and the sinking of inclined winzes along the dip, rather than the driving of tunnels from points below the lowest outcrops with the hope of tapping the veins at greater depth. The eastern and western zones of the principal group are well adapted to this method of development. The middle zone, located on the crest of a high ridge, could be easily worked through a tunnel cutting the vein at considerable depth, provided there was certainty of sufficient continuity and regularity in depth. The Franklin tunnel (see fig. 14) on the Florence Mining & Milling Co.'s ground, driven several years ago and inaccessible at present, is excellently situated for such development. It extends, according to private survey records of this company, almost directly under the outcrops on Edna Peak. A crosscut of 200 or 300 feet should cut the vein zone on its dip at a depth of 1,000 feet or more below the outcrops, and determine whether alunite in commercial quantity extends to so great a depth. It is also possible that examination of the walls of the tunnel may result in the discovery of one or more additional alunite veins, cut long before the identity and possible commercial value of the mineral was recognized.

While the steam-shovel method may be satisfactory for the removal of thick accumulations of débris from the surfaces of the veins, there are objections to its use in the direct mining of alunite, because a considerable amount of siliceous impurity will thus be included in the high-grade material. This lowering of the grade of alunite may not be sufficient to interfere seriously with the extraction of potassium sulphate, or with the use of the insoluble residue in the manufacture of refractory brick, or with the use of crude or calcined alunite as a fertilizer, but it will greatly increase the cost of the manufacture of metallic aluminum. Furthermore, the pronounced western dip of the veins would involve an increasing amount

of dead work in the removal of an increasing amount of waste from the hanging wall as depth increases.

ESTIMATE OF TONNAGE.

The quantity of potash (K_2O) available in the Custer vein was estimated by Butler and Gale[1] at 30,000 tons for each 100 feet of depth. The openings seen by the writer along the middle zone do not afford sufficient data for more than a rough estimate of the tonnage of alunite available, and those along the western zone and other prospects are too obscure and scattered to warrant any estimate. The following figures are intended only to give a rough idea of the quantity of alunite within the limits of the ground actually prospected. The number of short tons for each foot of depth is calculated by assuming a specific gravity of 2.82, or a weight of 175 pounds a cubic foot. These are the figures given in Bulletin 511, on page 12. The alunite in the exposures represented in the table is practically identical with that used for the determination of specific gravity.

Estimated tonnage per foot of depth in alunite veins in middle and eastern zones.

Location.	Proved length of vein.	Average width of high-grade alunite.	Surface area.	Quantity of alunite per foot of depth.
	Feet.	*Feet.*	*Sq. feet.*	*Short tons.*
Edna Peak to No. 10	900	10	9,000	788
Openings at Nos. 10 and 11	650	10	6,500	698
Openings at No. 14	200	15	3,000	263
Gillan-Custer group (Butler and Gale's estimate)				3,000
	1,750		18,500	4,749

If the recoverable potash (as K_2O) is estimated at 10 per cent, the prospects on the middle zone will yield about 17,000 tons of potash for each 100 feet of depth, somewhat more than half the amount (30,000 tons) similarly estimated by Butler and Gale for the openings on the Gillan-Custer group. Recent underground developments have shown that the Gillan-Custer deposit is much more irregular than was indicated by the surface workings. In some places high-grade alunite may be practically absent, and in others it is much thicker than the average thickness (10 feet) assumed in the estimate; but the estimate will doubtless stand as a reasonable and satisfactory minimum of workable alunite for this group of claims. Future developments on the middle zone may show similar irregularities, and the figures given above should be regarded as representing a preliminary moderate estimate.

[1] Op. cit., p. 12.

It should be borne in mind that only those openings have been included in the estimate where the practical continuity of the veins has been demonstrated or is highly probable. Further prospecting along the strikes of the different veins, especially that exposed on the L. & N. No. 4 claim, in the western zone, will probably increase considerably the proved tonnage of alunite. According to the above estimates, the tonnage of the middle and eastern zones may, for each 100 feet of depth, amount to about one-fourth of the annual consumption of potash in the United States, which, figured as K_2O, was more than 185,000 tons in 1913, the latest normal year.

DEPOSITS ON WEST SLOPE OF MOUNTAINS.

LOCALITIES.

A few deposits of alunite have also been reported from the west slope of the Tushar Mountains, but that at Sheep Rock, northeast of Beaver (see fig. 13, p. 238), is the only one visited by the writer and the only one from which specimens containing alunite have been seen by him. One deposit, about 2½ miles southeast of the Beaver River Power Co.'s plant in Beaver Canyon and 13 miles east of Beaver, was at first thought by its discoverer to be the dense white form of alunite but proved on examination to be kaolin, formed through the superficial decomposition of rhyolitic volcanic rocks. A chemical analysis of the material showed only 0.13 per cent of potash (K_2O). One or two other deposits have been reported, but nothing definite has been learned of them.

The Sheep Rock deposit is a quartz-alunite rock of too low grade to be of immediate commercial importance as a source of alunite but of sufficient scientific interest to merit a rather detailed description.

SHEEP ROCK DEPOSIT.

LOCATION AND EXTENT.

Sheep Rock is situated in the Newton mining district, at the west base of the Tushar Mountains, about 10 miles northeast of Beaver. (See figs. 13 and 15.) It is a bare-topped ledge of nearly circular form, about 900 feet in diameter, and has a gently rounded summit composed of nearly white quartz-alunite rock, which in part has weathered into clusters of rounded residual bowlders. These when seen from a distance bear a striking resemblance to a flock of sheep and have given rise to the name Sheep Rock. The first knowledge of alunite here was obtained early in 1914, when a specimen from the northern part of the ledge was sent to the United States Geological Survey by W. A. Wilson, then manager of the Sheep Rock mine, and was found by B. S. Butler to be a mixture of alunite and

quartz containing 30 to 40 per cent of quartz.[1] The writer visited the deposit in September, 1914, and the present description is based on his observations.

CHARACTER OF DEPOSIT.

The relations of the deposit to the andesitic country rock are very obscure. Its west, south, and north sides are covered with talus and brush and pass beneath the alluvium of the valley. The saddle connecting it with the andesite foothills is covered with float and affords no opportunity to study the contact in place. Study of

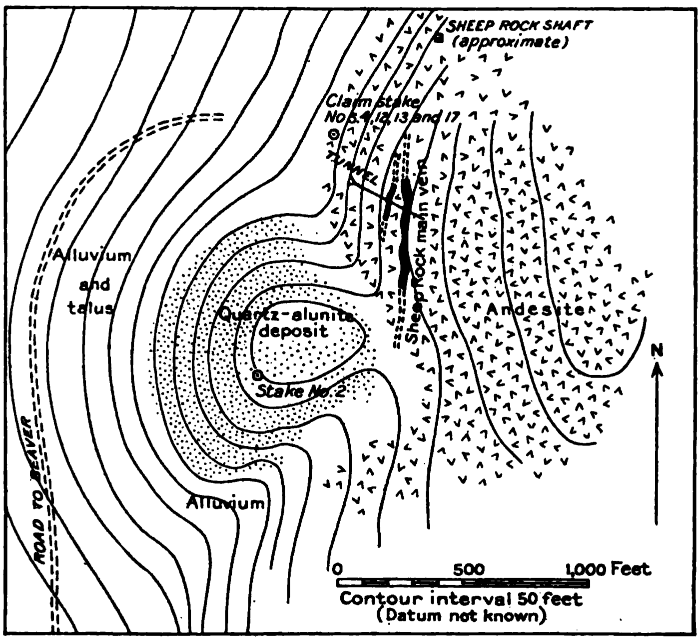

FIGURE 15.—Geologic sketch map showing relation of the Sheep Rock quartz-alunite deposit near Beaver, Utah, to country rock and metalliferous veins.

the float, however, shows that the two rocks merge within a short space, and that the Sheep Rock deposit was formed by the replacement of andesite. No definite connection with neighboring metalliferous quartz veins is apparent on the surface, and none has been made in the underground workings of the mine.

The material of the deposit as a whole is of uniform character, light-gray to pinkish color, and very fine grained, banded texture. A few textural variations, however, are present, including brecciated and concretionary phases and rock in which the porphyritic texture of the andesite is preserved. The alunite content also shows varia-

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[1] Phalen, W. C., Summary of potash salts for 1912: U. S. Geol. Survey Mineral Resources, 1913, pt. 2, p. 91, 1914.

tions ranging from 10 per cent or less up to 60 per cent, but as a whole appears to be rather uniform and to average about 30 per cent, equivalent to 3.5 per cent of potash (K_2O).

DETAILED DESCRIPTION.

The typical material of the deposit, as viewed from a short distance, appears grayish white, but most unweathered specimens when closely examined are found to have a faint to decided pinkish tinge, a dense to very fine grained texture, and a distinct though rather fine banding. The banding strikes and dips in various directions over different parts of the ledge and in many places is highly contorted, the contortions showing no apparent order of arrangement or relation to other structures, except where they grade into brecciated rock. As a rule, no mineral grains are recognizable megascopically, but the alternating bands are made up of relatively translucent and opaque material as much as a quarter of an inch thick. The translucent material has all the properties of microcrystalline quartz. The opaque material is of pale to moderate pink color and in many, if not most, places can be distinctly scratched by a knife blade. Short veinlets of smoky quartz, mostly an inch or less in length, are common between bands.

In thin section the banding proves to be due to alternating layers of relatively coarse clouded quartz grains and a very fine grained mixture of quartz and alunite. The coarser quartz grains are about 0.25 millimeter in diameter and are full of minute bubbles and specks. The alunite in the fine grained mixture forms minute but distinct laths evenly scattered among fine interlocking quartz granules. The fine and coarse quartz grains of adjacent bands have interlocking boundaries, but the alunite grains end abruptly against the coarse quartz grains. There are, however, a few relatively large alunite laths, as much as 0.5 millimeter in length, scattered among the coarse quartz grains. Minute grains of limonite, some distinctly oxidation products after pyrite cubes, are thinly scattered throughout the rock.

The brecciated variety consists of fragments of the typical finely banded rock cemented by a siliceous matrix. In thin section the fragments have the typical character and composition already described. A few veinlets of alunite are present in them but do not extend into the matrix, which contains no alunite. The relations suggest that the alunite belonging to the fragments recrystallized locally in fractures, but that no second supply of it was introduced after the shattering.

Close by stake No. 2 the rock contains numerous white translucent patches and streaks of chalcedonic quartz ranging from minute spots to linear streaks a foot in length. In thin section the quartz is in part very fine and even grained and in part composed of radiating crystals, which have evidently grown by replacement of the quartz-alunite rock.

At a few places, especially in the bowldery ground about 100 feet west of stake No. 2 (see fig. 15), the rock has a marked concretionary structure, and banding is inconspicuous or absent. The concretions are as much as an inch in diameter and present a variety of shapes but are not conspicuously different in megascopic character from the matrix. As seen in thin section, they consist as a rule of rudely fan-shaped alunite crystals as much as 0.5 millimeter long, inclosing minute grains of quartz and separated by minute linear aggregates of quartz. The matrix consists mostly of the very fine grained quartz sprinkled with minute alunite laths in roughly concentric arrangement, suggestive of crowding by the growth of the concretions.

The highest-grade material, which has a more distinctly pink color than the rest of the deposit, was found in the talus on the north slope of the area. It has in part the typical banded structure and in part a blotchy appearance, the predominating bands or blotches of pink alternating with others of gray color. Some of the gray blotches contain small cavities representing a dissolved mineral, probably feldspar. In thin section the pink part is seen to consist mostly of a mass of alunite inclosing minute grains of quartz. The alunite occurs mainly as a felty mass of minute laths, in which are scattered larger crystals, single or in feathery aggregates as much as a millimeter long. The relation of the larger to the smaller crystals suggests that the former have grown at the expense of the latter. Alunite makes up about 60 per cent of the whole. The gray areas consist of very fine quartz aggregates, the borders of which appear to have been partly replaced by alunite. The quartz areas contain a few grains 0.5 millimeter or less in diameter, which are evidently quartz phenocrysts practically unaffected during the replacement of porphyry by the quartz-alunite mixture; they also include a few minute grains and streaks of limonite, the grains preserving the cubic outline of original pyrite crystals.

Gradation into the country rock is marked by a pale-pink dense rock in which a few megascopic quartz grains and the outlines of original feldspar crystals are preserved. In thin section the feldspar phenocrysts prove to be largely replaced by fine aggregates of alunite, and faint outlines of original black silicates are suggested by fine quartz areas dusted with black specks and grains, the largest of which suggest pyrite. Quartz phenocrysts are very scarce. The groundmass is extremely fine grained and consists almost wholly of quartz with a little alunite and pyrite. This variety is similar to the altered wall rock of the Marysvale alunite veins.

RELATION TO METALLIFEROUS DEPOSITS.

The rock last described is very different from the altered wall rock of the main vein in the Sheep Rock mine, which is a typical sericitized andesite. The original minerals of this rock, both phenocrysts and groundmass, have been replaced by very fine grained mixtures of quartz and sericite, with about 3 per cent of pyrite in small grains. This rock contains gold to the extent of a few dollars to the ton and is classed as milling ore.

No microscopic alunite was found in the sericitized rock, and there was no opportunity to study the relations between sericitization and alunitization or between the metalliferous quartz vein and the quartz-alunite body. The vein is of the same type as the metalliferous veins in the Marysvale district, and it therefore seems probable that the quartz-alunite body bears the same general relation to it as the alunite veins in the Marysvale region are thought to bear to the neighboring metalliferous veins, but here, as in the Marysvale region, no direct connection between the two types of deposits has been proved. It is hoped that future development along the Sheep Rock vein will disclose the relation.

ORIGIN.

In view of this deficiency of critical evidence, any statement concerning the origin of the Sheep Rock quartz-alunite deposit must be regarded merely as a working hypothesis. The shape of the deposit and its position with respect to the neighboring metalliferous veins, especially the worked vein of the Sheep Rock mine, suggest that the rising vein-forming solutions were locally impounded and deflected along a permeable bed beneath some impervious layer of porphyry which is now removed by erosion. Physical conditions at this place were such that well-crystallized quartz and sericite, which characterize the metalliferous veins, were no longer formed. Instead the porphyry was permeated by silica, accompanied by the sulphate and sulphide radicles. These radicles converted the potassium and aluminum largely into alunite and a small amount of the iron into pyrite. It is possible that, as in the Marysvale veins, some potassium and aluminum were introduced by the solutions, but the average percentages of these elements in the Sheep Rock deposit, as shown by analyses 1 and 2, on page 263, is little, if any, more than those in the original porphyry.

The banded structure of the deposit bears a strong resemblance to that of the siliceous ores seen by the writer in the Tintic mining district and recently described by Lindgren,[1] who attributes the banding to diffusion in the replacement body of colloidal silica while the mass was still in a soft state. If this mode of replacement is accepted for the Sheep Rock deposit, the numerous contortions in the banding may be attributed to deformation before the mass became rigid, and the brecciated parts to deformation after the mass as a whole had become rigid but while there was still sufficient fluid or gelatinous silica to enter the interstices and cement the fragments.

Along the original margins of the deposit, where the replacing solution was weak or was more rapidly consolidated, there was evidently insufficient opportunity for complete replacement and development of banding, and the porphyritic texture of the replaced rock was preserved. The local concretionary structure evidently marks a tendency of the alunite to concentrate, possibly while the mass was still gelatinous. The presence of alunite in cracks later than the banding and the presence of large alunite crystals growing at the expense of small ones indicate a tendency of the mineral to concentrate even after the rock had hardened.

As contrasted with the Marysvale deposits, the Sheep Rock deposit was formed almost wholly by the replacement of porphyry, and the two minerals, alunite and quartz, were intimately mixed, whereas

[1] Lindgren, Waldemar, Processes of mineralization and enrichment in the Tintic mining district: Econ. Geology, vol. 10, No. 3, pp. 233–235, 1915.

those near Marysvale were formed for the most part in open fissures, with ample opportunity for the segregation of pure alunite, and only to a minor extent by replacement. This comparison does not imply that the available alunite was the same in each locality. The solutions in the Marysvale area may have contained a larger amount of the constituents of alunite, in addition to being favored with a better opportunity to deposit the mineral in segregated masses.

CHEMICAL COMPOSITION.

The three following partial analyses of the quartz-alunite rock, two of average samples and one the high-grade variety, were made by R. K. Bailey, of the United States Geological Survey:

Analyses of quartz-alunite rock from Sheep Rock deposit.

	1	2	3
Silica (SiO_2)	60.83	70.78	30.12
Sulphate radicle (SO_3)	13.83	10.56	26.53
Potash (K_2O)	3.89	2.90	6.87

1. Average sample at summit of Sheep Rock.
2. Average sample around stake No. 2 (fig. 15).
3. High-grade sample, north slope of Sheep Rock.

In analysis 1 the ratio of the sulphate radicle to potash is almost exactly that of pure potash alunite. Calculation from these data gives over 13 per cent of alumina and 35.6 per cent of alunite. In analysis 2 there is an excess of 0.6 per cent of the sulphate radicle over the ratio between the sulphate radicle and potash for alunite. This small excess may have been present in the soda alunite molecule. The calculated percentage of alumina is only 9.5 per cent and of alunite 25.7 per cent. In analysis 3 the excess of the sulphate radicle is 3.2 per cent. This also may have been present in soda alunite. The calculated percentage of alumina in No. 3 is 22.3 per cent and that of alunite 60.3 per cent.

COMMERCIAL VALUE.

The percentage of alunite, and therefore of potash, is much too low throughout most of the Sheep Rock deposit to be of any commercial value. Only in the talus at the north end of the deposit has material of promising grade been found, and only a little of this is in sight. Even the high-grade material, however, contains so much silica that, when compared with the practically pure alunite in the veins near Marysvale, the cost of crushing and calcining it, to say nothing of the cost of transportation, will probably be prohibitive for any but local use. The presence of alunite in the Sheep

Rock deposit, however, indicates that the solutions which deposited alunite were active in the extreme western as well as the eastern part of the Tushar Mountains and that the hills around Sheep Rock will be promising ground for alunite prospecting.

UTILIZATION OF ALUNITE.

PRODUCTS.

Although alunite has been mined for many years in foreign countries as a source of potash alum, the principal attention has been given to it in this country as a possible domestic source of potash. The extraction of potassium sulphate from it on a commercial scale appears now to have been accomplished. Possible by-products in the extraction of potassium sulphate are alumina and sulphuric acid. The successful production of the alumina or its derived products on a commercial scale appears to be a possibility, but there is no prospect of the production of sulphuric acid at present.

POTASSIUM SULPHATE.

As already stated, a demonstration by W. T. Schaller that the simple potassium sulphate instead of potash alum could be easily extracted from alunite simply by leaching the calcined mineral with water was published by the United States Geological Survey on January 9, 1912.[1] Schaller's observations are as follows:

> Laboratory experiments showed that on igniting the powdered alunite all of the water and three-fourths of the sulphuric acid are volatized. On leaching the residue with water the potassium sulphate is dissolved, leaving the insoluble aluminum oxide behind.
>
> The average amount of potassium sulphate leached from the ignited mineral powder is 17.9 per cent of the original material used. As the coarsely crystallized alunite was found to contain 19.4 per cent of potassium sulphate, 92 per cent of the total potash present was obtained by simple ignition and subsequent leaching.
>
> It is worth noting that, according to the laboratory experiments, 32.7 per cent of the ignited alunite consists of available potassium sulphate, which can be extracted by simple water leaching and evaporation. The remaining 67.3 per cent consists of nearly pure aluminum oxide.

Waggaman[2] found that a large quantity of water was required to free the ignited residue of alunite from soluble salts and that the subsequent evaporation was tedious and expensive, but the process has finally been worked out on a commercial scale by the Mineral Products Corporation. The following description of the process

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[1] U. S. Geol. Survey Bull. 511, pp. 58, 61, 1912; also announced in a notice given to the press for publication on Dec. 18, 1911 (U. S. Geol. Survey Press Bull. 80).

[2] Waggaman, W. H., U. S. Dept. Agr. Bur. Soils Circ. 70, 4 pp., July 31, 1912.

is based on information furnished by V. C. Heikes, of the United States Geological Survey, who saw the plant in operation.

From the ore bins at the mill the alunite passes through a gyratory crusher, then through a set of rolls, and thence is delivered to a storage bin. This material is mixed with powdered slack coal and is fed into a rotary kiln in which it is roasted. The roasted material is elevated to a storage bin from which it is drawn off into a digester. In the digester it is mixed with water and the sulphate of potassium dissolved out. The charges from the digester are stored in wooden tanks. From these tanks the mixture is pumped into a filter press where the insoluble alumina and the water-soluble potash are separated.

The solution is then evaporated in triple-effect vacuum pans. The sulphate of potassium crystals are separated out, drained, and dried. The dried powder is pulverized, screened, and sacked for shipment.

The boiler plant uses slack coal for fuel. Boilers having a rating of 600 horsepower produce steam for driving three engines, running the machinery of the plant. The exhaust steam is used for evaporating the solutions and drying the product.

The capacity of the first unit of the plant is estimated to be from 25 to 35 tons of sulphate of potassium a day. In addition to the valuable sulphate of potassium, the operators expect to gain some return from the filter cake left after the potash solution has been removed from the calcined material. This cake consists of nearly pure alumina and may be used for making refractory brick, for it is reported to withstand temperatures as high as 2,020° C. It may also prove to be available for making aluminum.

The mill is reported to be the first of its kind built in the United States to treat alunite, and operation of the first unit was begun on September 15, 1915, when some alunite was put through the crusher. Thereafter each part of the machinery was gradually tested until, by October 6, fully 200 tons of alunite had been distributed through the plant. On October 5 about 20 tons of filter cake reported to contain about 65 per cent of alumina (Al_2O_3) was discharged, and the saturated solution of potassium sulphate, about 85,000 gallons, had accumulated in the evaporators, which were placed in commission on October 6. On October 7 the first potassium sulphate was produced and was said to be about 99 per cent pure and 2 tons in quantity. On October 20 the first carload, aggregating 28 tons of potassium sulphate that analyzed more than 93 per cent pure, is reported to have been shipped in cotton bags to the Armour Fertilizer Works at Jacksonville, Fla.[1] Three cars are reported to have been shipped within the first month.

[1] Manufacturers' Record, Oct. 21, 1915, p. 52.

The mill is situated about 5 miles southwest of Marysvale and 2 miles west of Sevier River, near the mouth of Little Cottonwood Canyon. The alunite vein, on the Gillan-Custer claims, is 4 miles farther west by wagon road. The mined alunite is conveyed by an aerial tramway 6,200 feet long, with a fall of 1,900 feet, to a bin at the creek level, from which it is carried by wagons over a down-grade road of 3½ miles to the mill. The tramway, under present conditions, has a rated capacity of 12½ tons of alunite an hour.

Plans are reported for the erection of a plant by the Utah Potash Co. for extracting potassium sulphate and alumina from the alunite in the deposits of the Florence Mining & Milling Co.

POTASH ALUM.

Potash alum is a hydrous sulphate of aluminum and potassium ($K_2O.Al_2O_3.4SO_3.24H_2O$) containing 11 per cent alumina, 10 per cent of potash, 34 per cent of sulphur trioxide, and 45 per cent of water. The quantities and values of alum (principally potash alum) and aluminum sulphate produced in the United States from 1910 to 1914, inclusive, and the total imports of aluminum salts are shown in the following table:[1]

Production and imports of aluminum salts into the United States, 1910–1914, in short tons.

Year.	Production.						Imports.[a]	
	Alum.			Aluminum sulphate.				
	Quantity.	Total value.	Value per ton.	Quantity.	Total value.	Value per ton.	Quantity.	Value.
1910	9,090	$300,763	$33.09	126,792	$2,447,552	$19.30	2,127	$53,671
1911	10,468	329,686	31.49	134,077	2,743,336	20.46	2,283	56,833
1912	9,246	293,995	31.80	150,427	2,909,495	19.34	3,342	84,606
1913	9,605	312,822	32.57	157,749	2,977,708	18.88	2,702	66,549
1914	18,238	565,989	31.03	164,954	2,942,572	17.84	2,891	73,028

[a] Includes alumina, aluminum hydrate, or refined bauxite, alum, alum cake, aluminum sulphate, aluminous cake, and alum in crystals or ground.

The potash in the domestic alum is imported, and the alumina is derived from bauxite mined chiefly in Alabama, Georgia, and Tennessee, with small quantities from Arkansas. Only bauxite containing less than 2 per cent of iron oxide is used in the manufacture of alum, aluminum sulphate, and other aluminum salts. The plants manufacturing potash alum and other aluminum salts are all east of Mississippi River, but the practicability of establishing a plant in Utah is worthy of careful consideration.

[1] Phalen, W. C., The production of bauxite and aluminum in 1914: U. S. Geol. Survey Mineral Resources, 1914, pt. 1, p. 208, 1915.

The description of the process of manufacturing potash alum from alunite in foreign countries, which was reviewed by Butler and Gale,[1] is here repeated for the reader's convenience.

A considerable amount of alum is prepared from alunite. Alunite contains the elements of potassium alum, basic aluminum sulphate, and free alumina. In Sicily it is made into heaps and calcined in the open air. At Tolfa, where the manufacture is carried out on a larger scale, the roasting is conducted in furnaces like limekilns, lined with refractory materials. The mineral is heated in large pieces by the flame without direct contact with the fuel until sulphur dioxide begins to escape. The calcination requires about six hours, the mass losing about 35 per cent of water. During the ignition the excess of alumina beyond that necessary to produce alum is rendered insoluble and no longer has the property of precipitating basic sulphates from the solution. The calcined mass is exposed to the air upon a clay floor for some weeks, during which time it is occasionally moistened. The mudlike product is agitated in boilers with water at 70° C., and the clear decanted liquid, of density 10°–12° B., is evaporated to 32° B. and crystallized in small wooden tubs. The crystals are cubic, opaque, and reddish from the presence of ferric oxide. This iron is, however, quite insoluble and may be separated by recrystallization; the soluble iron is said to be less than 0.005 per cent. In this way "Roman alum" was formerly largely produced. On account of their great purity the red crystals were much sought after.

Alunite is now largely converted into alum by treatment with sulphuric acid and addition of potassium sulphate. Guyot[2] has examined this process and recommends the following method:

On ignition of alunite the free alumina is first rendered anhydrous and soluble in sulphuric acid; at a higher temperature the basic sulphates become soluble, but if the temperature be allowed to rise too high the alumina becomes vitrified and is insoluble. Guyot recommends ignition at 800° C. for three hours as the best means of rendering the maximum of both these substances soluble. The composition of the calcined mass is determined, and acid is used in proportion to the amount of soluble sulphate contained. For a product of the following composition, K_2SO_4, 14 per cent; $Al_2O_3.3SO_3$ (present as alum), 26.55; $Al_2O_3.3SO_3$ (free), 6.56; Al_2O_3 (free), 18.58; OH_2, 11.90; Fe_2O_3, 0.80; siliceous residue, 21.61 per cent, the proportions given below would be most satisfactory. Into a clay oven is poured 12.5 tons of sulphuric acid of 52° B. diluted to 30° B. and heated to 80° or 90° C. Eight tons of the calcined mineral is then added in portions and well stirred. After the whole has been added the liquid is left for two hours then evaporated to 38° B. and treated with 2.7 tons potassium sulphate. The process up to this point occupies 10 hours; after a further period of 13 hours the clear liquid is decanted off; its density should not exceed 42° B. The muddy liquid remaining is reduced to 24° B. by the addition of mother liquor from a previous crystallization, stirred, allowed to settle, drawn off clear, mixed with the first decantate, and crystallized in a vat. After one day the crystals are removed, redissolved, and recrystallized. The muddy residue is crystallized out for a further crop of alum. The total yield of alum is about

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[1] U. S. Geol. Survey Bull. 511, pp. 59–60, 1912; quoted from Thorpe, T. E., Dictionary of applied chemistry, London, 1890, p. 78.

[2] Guyot, M. P., Sur la richesse industrielle de l'alunite crue, en poudre: Paris Acad. Sci. Compt. Rend., vol. 95, pp. 693, 694; Expériences sur la calcination de l'alunite en poudre, destinée à la fabrication de l'alum et du sulfate l'alumine: Idem, pp. 1001–1003.

2.3 times the original weight of ore. The insoluble matter contains 3 per cent alumina and 2.01 per cent potassium sulphate, in addition to silica, etc.

According to C. Schwartz,[1] the best temperature for the roasting is 500° C., and the acid used should have a density between 1.297 and 1.530.

The summary concerning the utilization of the Australian deposit at Bullahdelah is contained in the following paragraphs:[2]

The following is a process by which alum is manufactured from alunite: The mineral is ground and then calcined in reverberatory furnaces, to dehydrate it and drive off part of the SO_3. It is next treated with a weak solution of sulphuric acid in lead-lined tanks, heated to boiling point by steam jets. The liquor is allowed to settle in the same vats, and the clear solution is run off into crystallizing tanks, which are kept in constant agitation while cooling, the alum crystallizing out and sulphate of alumina remaining in solution. The residue in the vat is boiled again with water, and the solution run off again in the same way. The liquor containing sulphate of alumina is then returned to the vats and sufficient of the calcined mineral added to completely neutralize any free acid. It is then heated to boiling point and ebullition continued until partial reversion takes place, the reversion being accompanied by a precipitation of the hydrated ferric oxide.

The alum, after collection, is washed and then refined in vats, similar to but deeper than those originally employed, and the concentrated solution is run into roaching tuns in which it is crystallized; it is then broken up and packed ready for the market.

The sulphate of alumina solution, after all the alum has been crystallized from it, is concentrated in small vats heated with steam coils, and the lower qualities of sulphate of alumina are formed by running the liquor onto lead tables and breaking the solidified material into blocks, the higher qualities (containing over 17 per cent of soluble alumina) being cast on copper trays. These higher qualities, which vary in color from yellow to green in the slabs, are then ground in a disintegrator, and the material assumes a snow-white appearance.

It is of course feasible, by the addition of K_2SO_4, to convert the whole of the alumina contained in the stone into alum if desired, but the more profitable method of treatment, when the better classes of sulphate of alumina can be sold at standard prices, is to make only so much alum as there is sulphate of potash present in the stone to produce, and convert the rest of the alumina into soluble sulphate of alumina (of commerce).

Sulphur may be obtained by distilling the mineral in the presence of any reducing gas like coal gas. Sulphuric acid may also be distilled from the mineral. Heating with carbonate of baryta produces aluminate of potash.

The following extract from a recent consular report[3] gives a little additional information on the industry at Bullahdelah:

The stone yields on an average 80 per cent of alum. According to the statistics for the mining industry of New South Wales, the output of alum for the years 1856 to 1908 was valued at \$450,000 and for 1908 to the end of 1913 \$190,000. Since the year 1908 about 1,200 tons of the rock have been taken out

[1] Ueber die Aufschliessung des römischen Alunits: Deutsch. chem. Gesell. Ber., vol. 17, p. 2887.

[2] Pittman, E. P., Alunite or alumstone in New South Wales: New South Wales Geol. Survey Rept., 1901, pp. 419–429.

[3] Sullivan, L. N. (consul at Newcastle, N. S. W.), Daily Cons. and Trade Repts. No. 199, p. 991, Bur. Foreign and Domestic Commerce, Aug. 25, 1915.

annually and shipped to England for treatment, where the alum could be extracted much more cheaply than was possible here. The Australian Alum Co. (Ltd.) is the operating company, with head offices at 109 Pitt Street, Sydney.

ALUMINA AND ALUMINUM PRODUCTS.

The possible derivation of alumina as a by-product in the extraction of potash from alunite has already been mentioned. Experiments on the direct extraction of alumina from high-grade alunite (see analyses 1, 4, and 5, p. 246) have shown that the process works well and may be a commercial success if freight rates from Utah to eastern aluminum-manufacturing plants are not prohibitive. As an offset to the freight rates, however, is the fact that the alumina produced from high-grade alunite is purer than the bauxite ores of the Southern States. The low-grade mineral, corresponding to analysis 2 on page 246, contains too much silica to be used as an ore of aluminum.

The question of erecting a western plant for extraction of aluminum may be found to deserve consideration. In a recent paper by Lyon and Keeny, of the United States Bureau of Mines,[1] the statement is made that " all processes for the extraction of aluminum from silicates are still very much in the experimental stage." As alunite is a sulphate, not a silicate, and can be obtained practically free from silica, its availability appears more promising. The extraction of both potash and alumina from the same lot of ore should apparently go further toward making a successful industry than the extraction of either product alone.

Other products, now obtained from the mineral bauxite, a hydrous oxide of aluminum, may also be derived from the residue left after the extraction of potassium sulphate from alunite. These are the different aluminum salts, refractory bricks, alundum (fused alumina), and calcium aluminate. In the manufacture of refractory bricks, the purer the alumina the more refractory the resulting product, but it is probable that the rather siliceous residues from the less pure grades of alunite, such as that represented by analysis 2, page 246, will be satisfactory for this purpose, whereas the residues practically free from silica are especially desirable for the manufacture of metallic aluminum. Alundum is used as an abrasive and is finding an extended use in the refractory industries. Calcium aluminate is used to give a quick set to plasters. It is possible that the alumina residue at the Marysvale plant may find a direct use, and it is reported that experiments to determine this point are under way. Further information on the production and manufacture of aluminum and its products is given in the annual reports on bauxite and

[1] Lyon, D. A., and Keeny, R. M., Electro-metallurgy of aluminum in the West (presented at September meeting of American Institute of Mining Engineers) : Abstract published in Min. and Eng. World Aug. 7, 1915.

aluminum by W. C. Phalen, of the United States Geological Survey, in Mineral Resources for the years 1908 to 1914, inclusive.

SULPHURIC ACID AND SULPHUR.

The manufacture of sulphuric acid in connection with the preparation of potassium sulphate and alumina has also been suggested, and in certain patents issued for apparatus for treating alunite means have been devised for conserving the fumes given off in roasting. It is stated by Phalen,[1] however, that owing to the expense of the process and to the small market for sulphuric acid in the West at the present time, it is very unlikely that the conservation of sulphuric acid from alunite will be seriously considered for some years at least.

It has been suggested that sulphur may be obtained by distilling the alunite in the presence of any reducing gas. The production of sulphur by such a method has evidently not been considered by those interested in the Marysvale deposits, and it is not likely to prove practical in view of the large amount of sulphur produced so cheaply in Louisiana and Texas, and for the further and important reason that the production of sulphur from its oxides (the "sulphur fumes" from smelters) has not yet progressed beyond the experimental stage.

FERTILIZER.

Owing to the slowness and expense of extracting potassium sulphate from alunite by leaching Waggaman[2] suggested that it might be more economical to use ignited alunite directly as a fertilizer. Experiments by Skinner and Jackson[3] afford some information on this question. These experiments show that raw alunite used in amounts equivalent to 25 to 500 pounds of K_2O per acre increased growth from 10 to 20 per cent. The growth when the raw alunite was used was not so good as with similar amounts of potassium sulphate and potassium chloride, but the increase in growth with calcined alunite ranged from 35 to 43 per cent, the average being 40 per cent, which was about the same as that with potassium sulphate and greater than that with potassium chloride.

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[1] Phalen, W. C., Potash salts, 1914: U. S. Geol. Survey Mineral Resources, 1914, pt. 2, p. 21, 1915.

[2] U. S. Dept. Agr. Bur. Soils Circ. 70, July 31, 1912.

[3] Skinner, J. J., and Jackson, A. M., Alunite and kelp as potash fertilizers: U. S. Dept. Agr. Bur. Soils Circ. 76, 5 pp., Apr. 10, 1913.

NOTES ON THE FINE GOLD OF SNAKE RIVER, IDAHO.

By J. M. Hill.

INTRODUCTION.

The material contained in this paper is largely a compilation from various sources, but is in part based on the writer's examinations of gravels in the Fort Hall Bottoms, near Fort Hall, Bingham County, Idaho, and near Moran, Lincoln County, Wyo. Its presentation at this time is thought to be warranted by a constantly increasing demand for information concerning the occurrence and recovery of the fine gold of Snake River. This short paper will probably be supplemented as the result of further studies which the writer expects to make in the preparation of a report on the placer deposits of the United States. The larger work will require considerable time for its completion and, with the cooperation of the Bureau of Mines, will include much more detailed information on the technology of placer mining than would be possible for a geologist to incorporate in a report.

BIBLIOGRAPHY.

Much of the material in this paper has been obtained from the publications listed below, which should be consulted by anyone desiring more detailed information concerning the gravels of Snake River.

Bancroft, H. H., History of Washington, Idaho, and Montana: Works, vol. 31, 1890. Mentions (p. 233) discovery of gold in Caribou district and says (pp. 531–534) that though gold was known in the gravels of Snake River prior to 1871, it was not until that year that any attempt was made to extract the gold.

Bell, R. N., Dredging for fine gold in Idaho: Eng. and Min. Jour., vol. 72, pp. 241–242, 1902; Idaho Mine Inspector, Eighth Ann. Rept., pp. 112–117, 1906. Describes construction of dredge.

——— The origin of the fine gold of the Snake: Eng. and Min. Jour., vol. 73, pp. 143–144, 1902. Supports Turner's suggestion that the fine gold of the Snake was deposited from the waters of a Miocene lake, and describes gold as occurring in small flakes, many of them cup shaped and coated with silica, of which 1,000 to 2,000 are necessary to make 1 cent. The rich gravels occur near the surface or in thin lenses of cemented sand and gravel.

Bradley, F. H., U. S. Geol. Survey Terr. Sixth Ann. Rept., pp. 250–271, 1873. Describes exploration of the headwaters of Snake River along Henrys Fork and Teton River and in Jackson Hole and the southern part of Yellowstone Park. Mentions early placer operations in Jackson Hole.

DAY, D. T., and RICHARDS, R. H., Investigations of black sands from placer mines: U. S. Geol. Survey Bull. 285, pp. 150-163, 1906. Give preliminary results of tests made at Portland Exposition.

—— —— Black sands of the Pacific slope: U. S. Geol. Survey Mineral Resources, 1905, pp. 1175-1258, 1906. Give final results of tests at Portland Exposition and show by tables the minerals contained in black sands. Give results of experiments on the separation of gold and platinum from such sands.

EGLESTON, THOMAS, The treatment of fine gold in the sands of Snake River, Idaho: Am. Inst. Min. Eng. Trans., vol. 18, pp. 597-609, 1889. Gives a very good description of the construction and operation of the burlap table machine.

IDAHO INSPECTOR OF MINES, Annual reports, 1899 to 1913. Notes on the occurrence and methods of working the fine auriferous gravels of Snake River.

IDDINGS, J. P., WEED, W. H., and HAGUE, ARNOLD, Geology of the Yellowstone National Park: U. S. Geol. Survey Mon. 32, pt. 2, pp. 184-189, 1899. Describe geology of the headwaters of Snake River and state that "It is quite likely that this gold [in Snake River and Pacific Creek] has in great part been derived from the conglomerate of the Pinyon (Eocene) formation."

IRVINE, C. B., Fine gold of Snake River: Min. World, vol. 29, p. 916, 1908. Notes fineness and high quality of Snake River gold, also its peculiar cupped flakes.

LINDGREN, WALDEMAR, The mining districts of the Idaho Basin and Boise Ridge, Idaho: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 625-637, 1898. Discusses geology of lower Snake River valley and shows the existence of a Miocene [Eocene?] fresh-water lake in which the Payette formation was deposited. Considers that flows of basalt took place in Pliocene and Pleistocene time.

—— The gold belt of the Blue Mountains, Oreg.: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, pp. 759-762, 1901. Mentions occurrence of gold in the gravels of Snake River between Idaho and Oregon and quotes W. H. Washburn at length on the distribution of gold.

MAGUIRE, DON, Snake River gold fields: Mines and Minerals, vol. 20, pp. 56-58, 1899. Notes that South Fork of Snake River is principal source of gold above Boise River, and estimates that gravels contain at least $2,000,000,000 in gold. Says that large operations have not as a rule proved successful, but that skim-bar miners average from $1 to $4 a day with rockers.

MINERAL RESOURCES OF THE UNITED STATES, published annually by U. S. Geol. Survey. The reports from 1902 to 1913 inclusive contain brief notes on the developments along Snake River and give production of gold from the various counties along the river's course.

POWELL, F., Gold dredging on Snake River in Idaho: Eng. and Min. Jour., vol. 70, pp. 395-396, 1900. Notes that highest gold content is confined to gravels for a few inches near the surface, and that tenor diminishes with depth. Describes the dredge used.

RUSSELL, I. C., Geology and water resources of the Snake River Plains of Idaho: U. S. Geol. Survey Bull. 199, 1902. Describes the geology of the lavas of the Snake River Plains between the Teton and Sawtooth mountains.

SCHULTZ, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: U. S. Geol. Survey Bull. 315, pp. 71-88, 1907. Describes occurrence of gold and methods of working gravels at the south end of Jackson Hole, Wyo., and other points on Snake River, particularly in that portion of the river between Minidoka and American Falls, which was partly submerged by the Minidoka reservoir.

—— Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 122-129, 1914. Describes placer mines at Pine Bar and Davis diggings, at south end of Jackson Hole.

Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267–282, 1913. Describes lode and placer deposits of the Caribou district, in the southeastern part of Bonneville County, Idaho.

Shockley, J. H., The origin of the fine gold in Snake River, Idaho: Eng. and Min. Jour., vol. 73, pp. 280–281, 1902. From examination of gravels of Snake River in Jackson Hole decided that gold came for the most part from the breaking down of auriferous pyrite similar to that found in andesitic bowlders. Says that all gravels carry gold but that bars with most sand carry largest amount.

St. John, Orestes, U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pt. 1, pp. 321–474, 1883. Describes exploration of part of upper Snake River basin, the Caribou district, and notes placer workings in Snake River canyon that were worked in 1875.

Washburn, W. H., Gold in Snake River gravel bars: Min. and Sci. Press, vol. 81, p. 610, 1900. Notes that gold is most abundant at head ends of bars deposited along short or inner sides of curves, and that these bars are enriched by every flood of river; that the top layer of gravels is richest; and that bedrock concentration is not usual. Mentions the fact that above Boise River 1,200 colors are worth 1 cent, but below Boise River it takes only 900 colors to make 1 cent, also that the gold above the mouth of Boise River is worth from $17 to $19 an ounce, while below it runs from $14 to $16 an ounce.

HISTORY.

There is no mention of the existence of gold in the gravels of Snake River in any of the reports of early explorations in this country. Different parties of the United States Geological and Geographical Survey of the Territories, under F. V. Hayden, visited Snake River. In 1871 Bradley [1] visited the headwaters and reported that as early as 1862 prospectors were trying to extract gold from the gravels of Snake River in Jackson Hole. Bradley says: [2]

> A considerable excitement was stirred up a few years since by reported discoveries of placer gold in large quantities on the upper Snake, and many prospectors visited this region. A small hydraulic operation was undertaken near this point, but the gold was too fine and in too small quantities to pay, and the whole region was entirely abandoned after a few months. The coarse gold found on the lower part of the Snake appears to have entered the river below the canyon, which is still to the southward of us.
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> * * * * * * *
>
> Two or three miles below the mouth of Salt River a small stream from the west (entering Snake River near the mouth of the canyon) was thick with mud from the Caribou gold washings.

In 1877 St. John [3] found "on the terraced interval [in the upper canyon of Snake River] indications of old placer workings which had been opened eight years ago [1875] by a party of miners associated with Jeff Stantiford, a well-known prospector and explorer of this region. The enterprise was, however, interfered with by the Indians,

[1] Bradley, F. H., Report of Snake River division: U. S. Geol. and Geog. Survey Terr. Sixth Ann. Rept., for 1871, pp. 190–250, 1872.

[2] Idem, pp. 266, 269.

[3] St. John, Orestes, U. S. Geol. and Geog. Survey Terr. Twelfth Ann. Rept., pt. 1, p. 196, 1883.

since when no organized mining operations have been resumed in this quarter."

According to Bancroft,[1] though flour gold was known to exist in considerable quantities in Snake River, it was not until 1871 that experiments were made toward its recovery. He says that paying quantities of gold were found—

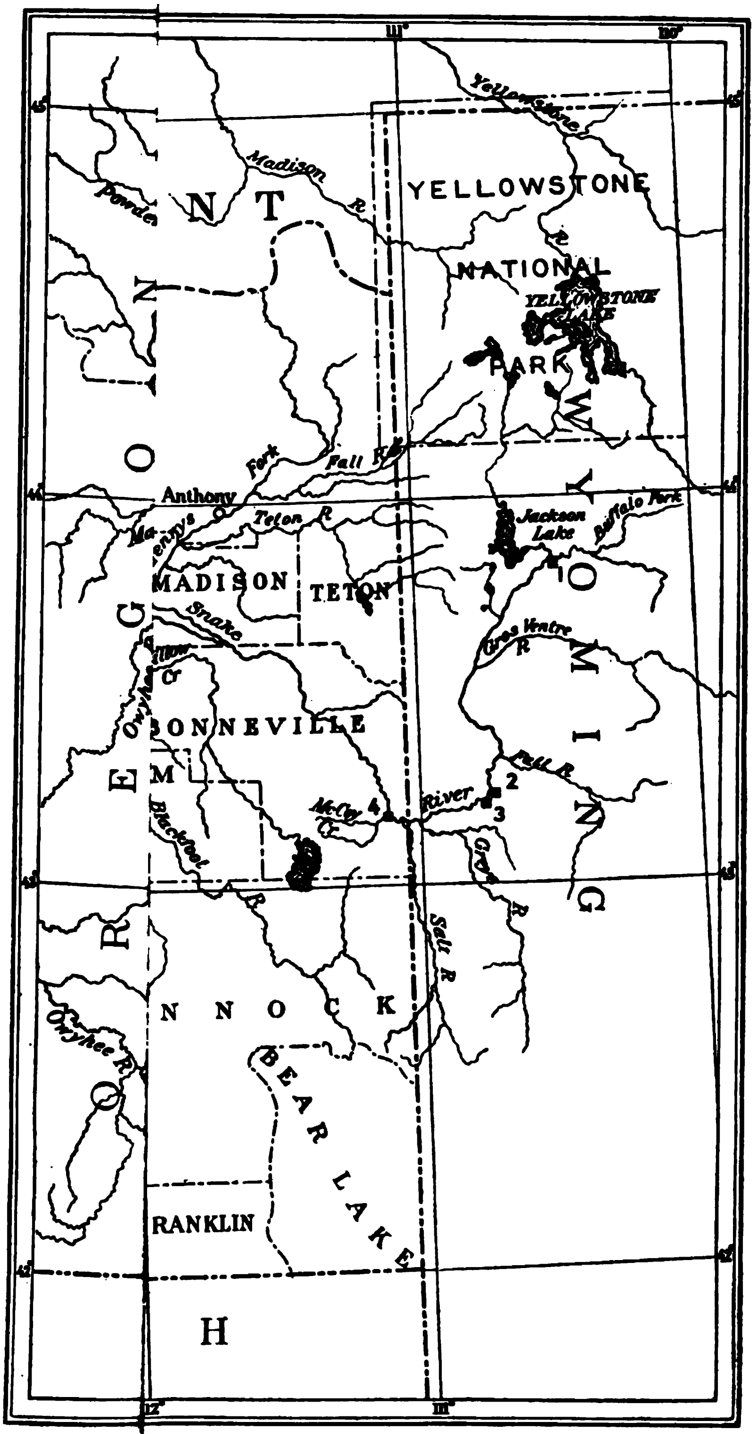
on the gravel bars in the vicinity of the Great Falls, at the mouth of Raft River, Henrys Ferry [between the mouths of Bruneau River and Castle Creek], and the mouth of Catherine Creek. * * * In 1871 and 1872 several mining camps or towns sprang up along the river. Thousands of ounces of gold dust of the very finest quality were taken from the gravels in their neighborhood in these two years. The placers, however, were quickly exhausted on the lower bars, the implements in use failing to save any but the coarsest particles. The higher bars were unprospected, and the camps abandoned. But about 1879 there was a revival of interest in the Snake River placers and an improvement in appliances for mining them and saving the gold, which enabled operators to work the high bars which for hundreds of miles are gold bearing.

According to Bancroft, the cost of opening a claim was about $5,000 and the returns from $10 to $50 a day; $5,000 to $10,000 in gold could be won from an acre of ground by gold-saving machines and amalgamators. He proposes the use of long ditches to supply water for the placers, as well as for irrigation. He says that on the Idaho Snake River Gold Mining Co.'s land in Black Canyon some rich ground yielded $100 a day to the man working with rocker, copper plate, and some cyanide of potassium, while the average yield was $25 a day over 80 acres of gravel. The Lawrence & Holmes Co. claims, near Blackfoot, paid from $19 to $50 a day to the man. Lane & Co., near the mouth of Raft River, obtained $25 a day to the man, and Argyle & Co., near Fall Creek, $100 a day to the man. The best working seasons, according to Bancroft, are from the 1st of March till the middle of May, and from the 1st of September to the 1st of November.

For many years the gravels of Snake River have been intermittently worked at a large number of places, extending from Moran, Wyo. (Buffalo Fork), to the mouth of Boise River. (See Pl. VII.) None of the larger operations, so far as known, have met with marked financial success, though unquestionably some individuals have made a small amount of money.

Probably the most extensive workings on Snake River were in southern Idaho, in the vicinity of Rupert, Minidoka, and American Falls. Plate VIII (p. 278) shows the principal claims in this area, some of which were submerged in the reservoir formed by the building of the Minidoka dam.

[1] Bancroft, H. H., History of Washington, Idaho, and Montana: Works, vol. 31, pp. 529-535, 1890.



CH PLACER WORK HAS BEEN DONE.

SNAKE RIVER BASIN.

GENERAL FEATURES.

Snake River rises in Shoshone, Lewis, and Heart lakes, in the southern part of the Yellowstone National Park. It flows southward, through Jackson Lake and Jackson Hole, for about 100 miles. Its principal tributaries in this part of its course are Buffalo Fork and Gros Ventre River, which enter it from the east. A short distance south of Jackson Hole the stream turns west, and after passing the Idaho line its course changes to the northwest. (See Pl. VII.) Between Fall River and a point a short distance west of McCoy Creek the river flows through a canyon, and in this part of its course Greys River and Salt River enter it from the south. Near the boundary between Madison and Jefferson counties, Idaho, Snake River is joined by Henrys Fork, a tributary that heads near the Idaho, Montana, and Wyoming boundary line. The river here makes a sharp turn to the southwest and continues in this direction to Rock Creek, beyond the town of American Falls. In this part of its course it receives Willow Creek, Blackfoot and Portneuf rivers, and Bannock Creek from the east, but no streams enter it from the Snake River Plains, which border it on the west. From Rock Creek Snake River flows in a general westerly course to the mouth of Bruneau River, a considerable tributary from the south. From American Falls to Salmon Falls the Snake receives no large tributaries from the north, but on the south side there are a number of streams, among which are Rock Creek, Raft River, and Marsh, Goose, and Salmon Falls creeks. Big Wood River joins Snake River a short distance west of Gooding, and from that point westward the Snake, here intrenched in a deep, narrow canyon, receives more tributaries from the north, heading in the Sawtooth Mountains, than from the south. Beyond the mouth of Bruneau River Snake River turns northwestward and continues in that course to the Idaho line, which it reaches about 30 miles west of Boise. It forms the western boundary of Idaho as far north as Lewiston and from that point flows in a general westerly direction to Columbia River near Pasco, Wash.

From an inspection of Plate VII it will be seen that Snake River and its tributaries drain all of southern Idaho and portions of western Wyoming and northern Nevada. The area of the Snake River basin above the mouth of Rattlesnake Creek is 37,300 square miles.

WATER SUPPLY.

According to a recent Survey report [1]—

Precipitation in the Snake River drainage area ranges from 6 or 8 inches in the valley to 50 inches at the head of many of the tributaries. In the higher altitudes the precipitation is practically all in the form of snow, but the snowfall in the lower

[1] U. S. Geol. Survey Water-Supply Paper 292, p. 287, 1913.

valleys below American Falls, Idaho, is comparatively light. * * * The temperature in these valleys ranges from 100° in the summer to 35° below zero in the winter.

The following tables showing the maximum, minimum, and mean discharge of Snake River at Moran, Wyo., and Blackfoot, Neely, and King Hill, Idaho, have been compiled from the Survey reports on the surface water supply of the North Pacific coast,[1] which give detailed information concerning the water resources of the Snake River basin:

Monthly discharge of Snake River at Moran, Wyo., and Blackfoot, Neely, and King Hill, Idaho.

Moran, Wyo.

[October, 1903, to September, 1911, inclusive.]

Month.	Discharge in second-feet.		
	Maximum.	Minimum.	Mean.
January [a]	1,070	374	654
February [b]	1,430	440	700
March	2,220	500	683
April	4,370	530	837
May	7,930	622	4,290
June	10,600	950	5,250
July	12,100	1,030	3,400
August	9,700	712	2,430
September	2,160	[c] 0	805
October	[c] 1,810	[c] 0	614
November	[d] 1,440	[e] 374	[d] 585
December	[d] 1,310	[e] 374	[d] 584

[a] Not including 1905 and 1907.
[b] Not including 1905.
[c] Not including 1910.
[d] Not including 1906.
[e] Not including 1906 and 1910.

Neely, Idaho.

[March, 1906, to September, 1911, inclusive.]

Month.	Discharge in second-feet.		
	Maximum.	Minimum.	Mean.
January	[a] 10,600	[b] 5,280	[c] 6,520
February [a]	12,800	5,270	6,460
March	15,600	4,140	7,540
April	29,900	5,460	11,000
May	33,000	10,500	19,000
June	41,100	6,130	25,600
July	37,200	3,470	14,100
August	13,900	2,220	5,930
September	11,100	3,450	6,070
October	8,870	4,270	6,480
November	13,200	5,050	7,030
December	[d] 7,590	[e] 5,320	6,650

[a] Not including 1910.
[b] Not including 1907, 1910, and 1911.
[c] Not including 1907 and 1910.
[d] Not including 1909.
[e] Not including 1908, 1909, and 1910.

Blackford, Idaho.

[June, 1910, to September, 1911, inclusive.]

Month.	Discharge in second-feet.		
	Maximum.	Minimum.	Mean.
January [a]	5,870	2,140	3,250
February [a]	7,270	2,270	3,870
March [a]	5,620	2,200	4,000
April [a]	9,450	3,610	4,960
May [a]	18,800	9,170	14,800
June	32,900	3,560	16,900
July	21,900	890	6,580
August	6,860	238	2,000
September	3,700	1,120	2,340
October [b]	2,900	1,570	2,430
November [b]	3,780	2,900	3,410
December [b]	3,870	2,270	3,230

[a] 1911 only. [b] 1910 only.

King Hill, Idaho.

[May, 1909, to September, 1911, inclusive.]

Month.	Discharge in second-feet.		
	Maximum.	Minimum.	Mean.
January	21,400	8,160	10,000
February	18,700	8,750	11,400
March	25,100	8,880	16,200
April	30,100	8,720	16,800
May	34,000	12,900	21,900
June	41,900	5,790	26,200
July	37,500	4,760	13,100
August	20,900	4,760	6,780
September	15,600	5,090	8,460
October	14,700	6,400	10,500
November	15,800	6,750	11,700
December	14,400	7,910	11,000

[1] U. S. Geol. Survey Water-Supply Papers 100, 135, 178, 214, 252, 272, 292, 312.

PLACER GRAVELS.

DISTRIBUTION.

The placer gold deposits along Snake River may be classed as stream placers and bench placers. The stream placers consist of bowlders, gravels, and sands that form bars, banks, fills, and shoals along the present streams. Many of these deposits are temporary and change more or less during every heavy storm. The bench placers are older stream deposits, at higher levels represented by terrace remnants.

At the mouth of Buffalo Fork (No. 1, Pl. VII) there are two distinct terraces 10 and 30 feet above the present channel. South of Jackson Hole examples of terrace formation are seen on both sides of Snake and Fall rivers, at wide points in the valley. At several places along Snake River above the canyon terraces occur 50 to 100 feet and even 200 feet above the river. The terraces slope gently toward the center of the valley and their slopes are strewn with waterworn rock fragments similar to the material found in the river bed. Many of the terraces along Fall River, extending back a quarter to half a mile from the present river channel, are paved with waterworn pebbles similar to the material found in the Snake River channel. Near the mouth of Fall River, where the stream cuts across two anticlines, gold was found in the sands accumulated near the water's edge. Whether gold occurs in the gravels farther up Fall River above the canyon and along its tributaries heading in the Gros Ventre Mountains is not known.

In the canyon between Greys River and McCoy Creek (No. 4, Pl. VII) there are several small gravel deposits both in the present channel and on rock-cut terraces.

At Market Lake (No. 5, Pl. VII), near the junction of Henrys Fork and Snake River, there are extensive bottoms. Terrace gravels about 15 feet above the present channel, as well as the gravels now at the stream level, have been worked in the past.

On both sides of Snake River near the mouth of Blackfoot River considerable gold has been won from terrace gravels on the Welch ground (No. 6) and the Gold Point and Eagle Bend ground (No. 7). On the Welch ground, east of the river, the gravel bank is 18 feet high, and no bedrock is exposed in the workings. It is said that a 75-foot well near the river cuts only gravels and sands. On the west side of the river the gravels, which rest upon basalt, range from a few inches to 12 feet in thickness. Several attempts to work the present stream gravels in this vicinity by the use of dredges and suction pumps have not been successful.

In the Fort Hall Bottoms and on Horse Island (Nos. 8 and 9, Pl. VII) some gold is won from "skim bar" diggings in the present

channel and from gravels occupying a terrace about 8 feet above the present level.

Between American Falls and the Minidoka dam there are a number of placer bars both in the stream channel and on terraces from 15 to 30 feet above the old water level. These bars have been productive, particularly Diamond Bar. As will be seen from an inspection of Plate VIII, part of the productive ground was submerged by the Minidoka reservoir. Between Burly and Milner there has been some placer work, but the backwaters from the Milner dam have submerged the bars, and no work has been done there recently.

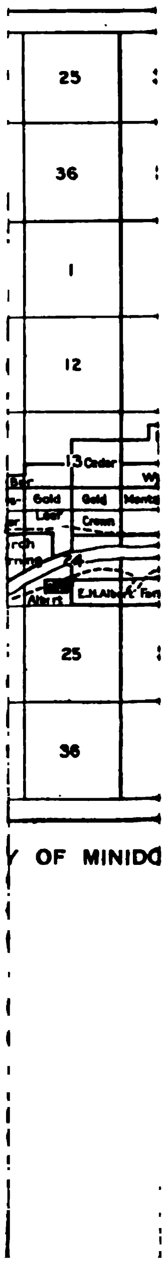
In the vicinity of Clear Lake and Blue Lake (Nos. 13 and 14, Pl. VII), north of Twin Falls, there are gold-bearing gravels, some of which are on terraces.

At King Hill and Glenns Ferry (Nos. 15 and 16) several attempts to dredge the present stream gravels have not proved financially successful. In the canyon between King Hill and Guffeys there are a number of bars that have been worked in the past. It is thought that most of these gravels are in the present stream channel, though little information is available concerning the operations on this part of Snake River.

CHARACTER.

The gravels of Snake River consist for the most part of white, cream-colored, and gray quartzite pebbles, with some pebbles of dark slates and a few of white quartz and red and gray flint. Pebbles of granular and fine-grained igneous rocks and schist occur in the Jackson Hole country and in less numbers along the lower part of the river. Small amounts of sandstone and limestone pebbles are found in the gravels below Gros Ventre River, and basalt pebbles are seen in the gravels below Henrys Fork. The sand accompanying the gravels is composed in the main of quartz grains and heavy minerals. In most places there are grains of a black sand that is light in weight and can be washed away from the heavy "black sands." This sand is apparently in part disintegrated basalt and in part volcanic glass lapilli. It is not found, so far as known, above Henrys Fork. The largest deposits of light-weight black sand are usually found beyond or on the downstream ends of the "skim bars."

The gravels are of two fairly distinct sizes and are more or less sorted. By far the greater in amount are the relatively coarse gravels, such as are most abundant in the present river channel. These are composed of well-worn ovoid to round pebbles, ranging in general from one-fourth inch to 4 inches in diameter and averaging 2 to 3 inches, but accompanied by a small percentage of larger bowlders and considerable light-colored sand. Lying in small lenses in the coarse gravels and on the tops of the high bars of the present Snake River channel are smaller deposits of fine gravels, whose peb-


25
36
1
12
13 Cedar
Gold
Gold
Crown
E.H.Albert
Albert
25
36
OF MINIDO

bles range mostly from one-fourth to 1 inch in diameter, only a few pebbles reaching 2 inches. The fine gravels are everywhere mixed with a much larger quantity of heavy sands than the coarse gravels and carry more gold. These gravels are locally known as the "skim-bar" gravels. The terrace gravels contain lenses of fine gravels that are believed to be old skim-bar gravels. In some places they are cemented with a white to gray lime carbonate, but in others they are uncemented.

GOLD.

DISTRIBUTION.

Usually the soil covering the gravels is not gold bearing, though in the region of Minidoka and American Falls, according to Schultz,[1] "it was found that in general the values were concentrated in the bottom of the loam and the upper portion of the underlying gravels."

The gold is most often found in appreciable amounts in the gravels of the terrace and present stream deposits and is more abundant in the fine gravels, those averaging one-fourth to three-fourths of an inch in diameter, than in the coarser material.

The coarser gravels that are so widespread along the present channel of the Snake carry from a few to as many as 1,300 colors to the cubic yard. The gold is not equally distributed throughout the coarse gravels, either laterally or vertically. In fact, there seems to be a concentration of gold in the upper layers of the coarse gravels.

The most valuable gravels found along Snake River, comparable to skim-bar gravels, are much finer than the average material handled by the river. The pebbles range from one-fourth to 1 inch in size, but most of them are between one-fourth and three-fourths of an inch. With these gravels there is in all places a considerable quantity of black sand, a larger proportion than is found with the coarser gravels. The gold content of the skim-bar gravels is not equally distributed over the skim bar. The richest gravels are found in the outer edges of the bars, where the gravels "tail off," and to a depth of 6 to 8 inches only. The rich gravels consist of heavy particles carried, probably in suspension, by strong currents during high water and deposited at the edges of the higher bars, where eddies have retarded the currents or where the carrying capacity of the water is checked by the lessening of the depth of the channel. These relations will, perhaps, be better understood by reference to figure 16. All the material on the skim bars looks very much alike, and it is only by testing that the richest portions, those usually worked by the skim miners, can be determined. As will be seen from the sketch, the area of skim-bar gravels is small compared to the area of a bar.

[1] Schultz, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: U. S. Geol. Survey Bull. 315, p. 82, 1907.

Gold is present in the gravels found at various places on the high terraces. The gravels are essentially the same as the coarse gravels in the present river channel and carry as much gold. The lenses of fine gravel in the terraces, corresponding to the skim-bar gravels of the present stream, have been found to yield more gold than the coarse gravels. In some places where terrace gravels have been worked lime-cemented lenses that usually carry more gold than the average gravels have been found.

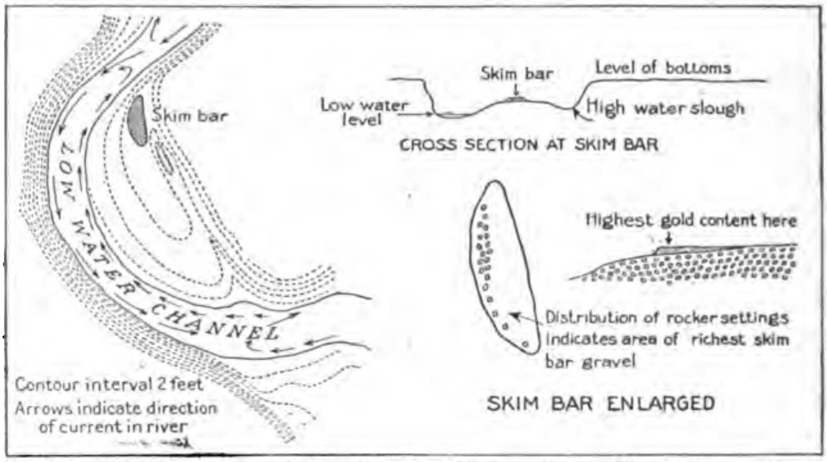


FIGURE 16.—Sketch showing relation of skim bar and distribution of gold in skim-bar gravels.

CHARACTER.

The Snake River gold is in minute particles, most of which are flat. The largest pieces are scarcely 0.01 inch in diameter, and the colors range from those of that size to some so small that the separate flakes can be distinguished only with a high-power microscope. The large flakes as a rule are somewhat cupped, apparently owing to the turning up of their edges by repeated knocks. This characteristic was noted in most of the colors separable by the eye. Most of the microscopic colors are flat, but some are rounded irregular grains.

Most of the gold has a bright-yellow color, but certain flakes appear red-brown in some lights. In part the color of the rusty gold appears to be due to a roughened surface, but some of the larger flakes of brown color have a thin coating of brown material that is probably iron hydroxide. Bell[1] reports that some of the gold is coated with a sugary incrustation of silica or other substance, which gives the flakes a light color.

The gold from Snake River is from 0.930 to 0. 951 fine and averages about 0.945, according to most reports. The particles are so small that it takes from 1,000 to 2,000 colors to be worth 1 cent.

[1] Bell, R. N., The origin of the fine gold of the Snake: Eng. and Min. Jour., vol. 73, pp. 143-144, 1902.

PRODUCTION.

It is impossible to ascertain the amount of gold obtained from the gravels of Snake River during the early years, as the figures for the output of Snake and Salmon or Boise rivers are combined in the reports of the Director of the Mint. Since 1902, according to statistics published by the United States Geological Survey, $149,315 in gold has been taken from Snake River above the mouth of Boise River. Of this recorded production, $29,658 was obtained from placers in Bingham County, $57,408 from Cassia County, $11,078 from Lincoln County, and $12,171 from Twin Falls County.

It is probable that these figures do not represent the total value of gold obtained from the gravels of Snake River, because of the great uncertainty as to the number of operators working these gravels. As is well known, much of the gold is obtained by rocking, and it is impossible to know of or hear from each person who may have worked the deposits for a few days or longer. It is thought that much of the gold obtained by these small operators is used to obtain supplies from merchants, and its source is lost sight of when the merchants turn it over to banks, assay offices, or the mint.

PLATINUM.

The experiments of David T. Day, then of the United States Geological Survey, at Portland, Oreg., on the heavy placer concentrates of the Pacific slope, to determine their value in other metals and minerals besides gold, included a number of samples of Snake River concentrates, nearly all of which yielded from a trace to an appreciable amount of platinum, but it is doubtful whether many of the results were obtained from representative samples. The platinum is probably too thinly scattered along this stream to be of much value, though it may be combined with the concentrates and have largely passed unnoticed.

Bell[1] reports that one sample of Snake River concentrates which yielded 0.018 ounce of platinum and several hundred dollars' worth of gold to the ton was obtained from a burlap table and probably represented a concentration of several thousand to one. A sample of concentrates taken from the same deposit, from which the free gold had been amalgamated, yielded only $3 in gold and a trace of platinum to the ton.

That platinum in metallic form is associated with the gold in the gravels can not be questioned, for although it can rarely be seen in panning it invariably shows in cleaning amalgam. In the operation of the Sweetzer-Burroughs dredge near Minidoka it was always observed at clean-up time as ashy gray metallic particles which

[1] Bell, R. N., Eighth annual report on the mining industry of Idaho, for 1907, p. 115.

floated when the amalgam was thinned with quicksilver for the purpose of separating foreign matter from the gold. A quarter of an ounce of clean platinum recovered in this manner is now in the possession of Lewis Sweetzer, of Rupert, Idaho. It is perfectly clean gray metal in scaly particles about as minute as those of gold.[1]

HEAVY MINERALS.

The results of the tests made by David T. Day on concentrates from placer gravels were published in 1906.[2] The following table, compiled from Day's report, shows the minerals he obtained from Snake River concentrates:

[1] Schultz, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: U. S. Geol. Survey Bull. 315, p. 38, 1907.

[2] U. S. Geol. Survey Bull. 285, pp. 150-164, 1906; U. S. Geol. Survey Mineral Resources, 1905, pp. 1175-1246, 1906.

Heavy minerals in concentrates from gravels of Snake River.

[Pounds per ton, except gold and platinum, which are stated in dollars per ton.]

Locality.	Magnetite.	Chromite.	Ilmenite.	Garnet.	Hematite.	Olivine.	Monazite.	Limonite.	Zircon.	Quartz.	Unclassified.	Gold.	Platinum.	Remarks.
Bingham County:														
Rich	48		64	10					16		1,878	$25.10		65 pounds to the cubic yard of gravel.
Otis	70		36						50	1,536	310	1.24		Concentration not known.
Rich	290		90	38						1,448	132	61.02		1½ pounds to the yard of gravel, ground sluice.
Blackfoot	1,118		616	50					150	14	50	674.26		35 pounds to the ton of gravel.
Do	726		436	356	a 152				174	36	120	73.38		Concentration not known.
Sand of Snake River	688		138						Trace.	614	560	405.55	$5.40	Do.
Do	864		664						112	200	136	33.07	21.00	1½ pounds to the ton of tailings, ground sluice.
Do	888		112						160	840		62.63		1 pound to the yard of gravel.
Do	1,032		80		40		Trace.		80		768	1,154.37		Concentration not known.
Blaine County:														
Snake River near Wapi	72		39	17		11			8	1,317	533	.71		Not concentrated.
Lincoln County:														
Minidoka												5.37		Wilfley concentrates.
Minidoka, Snake River	1		Trace.	Trace.	b Trace.				Trace.			.08		Natural sand.
Minidoka	2		Trace.	Trace.	b Trace.				Trace.			.10		Do.
Do	4		Trace.	2	b Trace.			Trace.	Trace.			.13		Do.
Do	8		4	4								1.45		Do.
Do	Trace.		Trace.	Trace.			8		Trace.			.41		Diaspore; 66 pounds of apatite.
Shoshone	174	15		80			26		46	1,441		26.33		50 pounds a day.
Snake River near Milner	1,976										24		None.	
Do			16	500					152	152	1,130	9.51		30 pounds to the ton after amalgamation.
Do	100										1,900	39.89		20 pounds a day.
Near Wapi	Trace.		Trace.							1,784	215		$0.31	Natural sand.
Oneida County:														
American Falls	48		24							1,538	390	114.20		Taken from sluice box.
Do	14		4	2		6				1,488	488	.62		Natural sand.
Do	9	2		8		18				1,335	628	Trace.		Natural sand, old river channel.
Owyhee County:														
Enterprise	648										c 1,352			6 pounds to the yard.
Oreana	1,344		280	312					56					1 pound to the yard.
Do	32		1,472	40			56			340	80	2.19		Concentration not given.
Sand of Snake River	51		9	6		4			2	1,432	493	1.12		Natural sand.
Do	48		7	4		6			1	884		.98		Do.

METHODS OF MINING.

Along the course of Snake River can be seen the wrecks of numerous attempts to extract the fine gold from the gravels. The remains of dredges are seen here and there, and many more have been removed. Countless "process machines" have been tried on Snake River, but so far as known without success. Most of these "machines" have depended on amalgamation, but many different methods have been used to get the quicksilver and gold into contact.

The rocker and sluices are still used, and a sluice of special type, known as the burlap table, used also on some of the dredges, has proved one of the best appliances for saving the fine gold. (See fig. 17.) In working with burlap tables the main sluice leading from the working (A, fig. 17) is set at any convenient grade. Near the lower end is a section with a perforated steel bottom (B, fig. 17), which allows the fine heavy sands and gold to drop through to sluices set at right angles to the line of the main sluice. The transverse sluices (C, fig. 17) are in reality launders which deliver the sands to a series of burlap tables (E, fig. 17). Each burlap table is from 16 to 30 feet long and 3 or 4 feet wide. It is usually set at a grade of 1 inch to 12 inches, but the grade needs to be adjusted to meet different conditions. Most tables are built with two drops at least. The pulp from the launder sluices is fed to the burlap tables through adjustable openings (D, fig. 17), so that it flows over the table in a thin, even sheet. The heavy sands and gold are caught by the rough surface of the burlap, and the light sands run to waste. In some places the tailings are rerun. In operation the tables are cleaned as often as necessary, by taking up the burlaps and washing them in tubs of clear water. These concentrates, together with those washed from the bottom of the tables, are either placed in a grinding pan or revolving barrel, for treatment with quicksilver and weak cyanide solution, or cleaned with a rocker. The latter method, while attaining somewhat better results than the simple rocking of the gravels, is not efficient. In some of the burlap tables the first section of the table—that nearest the launder sluice—has a silver-plated copper bottom coated with quicksilver, for amalgamating the gold. In figure 17 six tables are shown on each side of the main sluice. The number of tables varies with different conditions. In some places all the tables are on one side of the main sluice. In fact, each operator has his particular design of table and method of handling the gravel.

Both suction-pump and bucket dredges have been used for lifting the gravels. Probably the most successful dredging operation on the river was the Sweetzer-Burroughs dredge, which was operated

30 miles west of Minidoka. The first dredge [1] built by this company, in 1894, was of the suction type, but the company later built a bucket dredge [2] having a capacity of 2,000 cubic yards a day. The concentrates from burlap tables were amalgamated in barrels. It

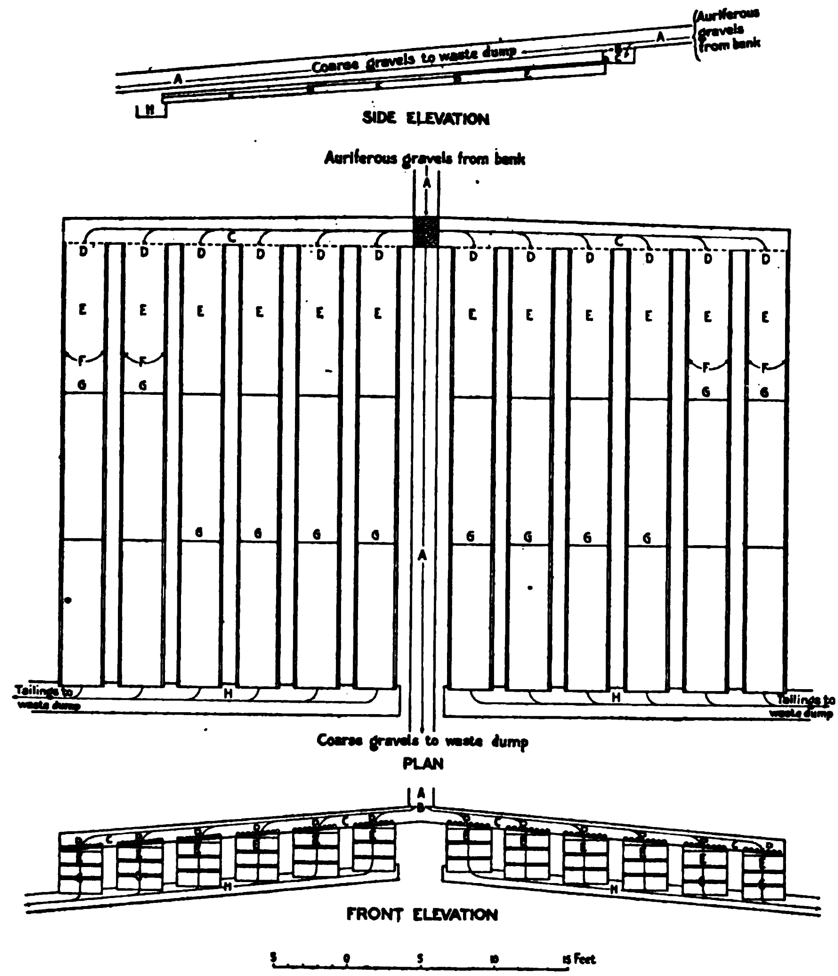


FIGURE 17.—Diagram of burlap table for saving fine gold.

is estimated that the cost of handling the gravels ranged from 4½ to 5½ cents a cubic yard.

Within the last few years experiments at cyaniding the gravels of Snake River, while not meeting with financial success, have at least showed that the method is not without some merit. At a plant located about 16 miles southwest of Blackfoot the gravels were

[1] Bell, R. N., Dredging for fine gold in Idaho: Idaho Inspector Mines Rept. for 1904, pp. 48–52, Min. and Sci. Press, vol. 94, pp. 542–543, 1907.

[2] Powell, F., Gold dredging on Snake River in Idaho: Eng. and Min. Jour., vol. 70, pp. 395–396, 1900.

screened through a $\frac{3}{16}$-inch mesh trommel. All the undersize was leached, and it is said that no difficulties were encountered in the leaching tanks.

TYPICAL LOCALITIES.

More detailed notes about some typical deposits of gravels are included in the hope that they may give a better understanding of the character of the deposits and the distribution of the gold. The numbers in parentheses refer to corresponding numbers on Plate VII.

BUFFALO FORK (No. 1).

Several placer claims were located along Snake River south of Buffalo Fork, at the north end of Jackson Hole, Lincoln County, Wyo., in 1905. These claims are between Elk and Moran post offices and cover low terraces on the east side of Snake River, in the southwest quarter of T. 45 N., R. 114 W., and the north half of T. 44 N., R. 114 W., of the sixth principal meridian.

In this locality there are two well-marked terraces above the present channel of Snake River. The first terrace is 10 feet and the second 30 feet above water level. The upper terrace is covered with 2 to 6 feet of sandy loam, which overlies 6 to 8 feet of gravel, which in turn rests upon a stratum of clay extending below the level of the lower terrace. In the sandy loam a color of gold is found here and there, but the gravels contain more gold. A series of tests of these gravels, made by the writer in 1908, show the average value of the gravels of the upper terrace to be less than 1 cent a yard, though in places, particularly just above the clay, the gravels carry more gold.

In the lower terrace gravels similar to those in the present channel are found throughout to the level of the river. They contain more gold to the yard than the gravels of the upper terrace, averaging about 2½ cents, but in places carrying as much as 5 cents a yard.

Skim bars, some of which have been worked, are present on the upper ends of the high-water bars in the present channel.

A small quantity of the gravel of the upper terrace has been worked by sluicing, and there are evidences of a little work having been done on the lower terrace and the skim bars.

BAILEY CREEK (No. 2).

The following notes are taken from papers by Schultz:[1]

The placer workings on the Davis claim are on a low terrace along the east side of Snake River, extending half a mile north from the mouth of Bailey Creek. They are in the vicinity of those opened by Stantiford in 1870. There are two distinct

[1] Schultz, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: U. S. Geol. Survey Bull. 315, pp. 77-78, 1907; Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 124-127, 1914.

terraces here, and Mr. Davis is at present working parts of both. The very fine flour or flake gold occurs all through the gravel, but is much more abundant in some streaks than in others. Mr. Davis, who has been mining in Idaho for 40 years and has been working this bar for several years, makes the following statement concerning the gold placers:

"I always found, in working the high bars of the river, that they contain from one to two and sometimes three pay streaks, with fine gold scattered throughout the gravel both above and below the pay streaks. Most all of these high bars have streaks of pay. Sometimes in old eddies or whirlpools the deposits do not seem to have any regular pay streaks. The gold in these places seems to be deposited uniformly and the entire deposit pays well.

"The gold-bearing sand and gravel in my richest pay streak at the Davis diggings or Bailey Creek mining camp average from 3 to 7 feet in thickness and lie on a bed of white cement rock or clay. The gold in this pay streak runs from 9 cents to $3 per cubic yard. The average height of the bar or bank that is here worked is 20 feet. From the top of the lower pay streak to the top of this bank is a 13-foot sand and gravel bed which averages 3 cents to 25 cents in gold per cubic yard. The width of the pay streak is about 500 feet and extends beyond the limits of my workings, which are about 900 feet at this place. South of the 'machine' near the central ditch the pay streak is considerably wider. Six hundred feet north of the central ditch the gravel bank is 30 feet high, the pay streak wider, and the entire bank runs higher in gold values."

* * * * * * * *

One of the main pay streaks near the Snake River channel is from 4 to 6 inches thick and is overlain by 4 to 6 feet of gravel that contains much lower values in gold, and is in turn overlain by a nearly barren gravel bed 4 to 5 feet thick that extends to the surface. The rich pay streak, from 8 to 10 feet below the surface, makes it profitable to work the entire bank. On working back into the bank away from the river these seams are found to rise and a new pay streak about 6 feet thick and richer than the other one is encountered. The new pay streak drops slightly farther east and probably represents the deposits of an older channel of Snake River. The different placer mines and even parts of the same terrace vary considerably in the character of the deposits and arrangement of their beds.

Water for hydraulicking is brought in a ditch from a point some distance up Bailey Creek and is used to break down the gravel, wash out the gold and fine particles, and sluice through the flume (and burlap tables). Sometimes the gravel is shoveled into sluice boxes. Large bowlders are piled up in rows between the boxes so as to retain as much grade as possible and still work the lower pay streaks.

The gravel on these terraces, as shown by the workings for the last few years, runs from 3 cents to $3 a cubic yard. Pay streaks that run $2 to $3 a cubic yard are very thin and rare. The average aggregate run of the pay streaks and the comparatively barren gravel is 7 to 10 cents a cubic yard. Only one piece of coarse gold, said to be about half the size of a tenpenny nail, has thus far been found.

Four samples of black-sand concentrates collected by the writer [Mr. Schultz] from the Davis diggings were examined by David T. Day, who says:

"These samples consist largely of magnetite—No. 1, apparently not much concentrated, containing 1 ounce of magnetite to 4½ ounces of the original material. They are all rich in gold but contain no platinum. The percentage of gold was not determined, but they will all range from $30 to $100 a ton and probably more. This gold could easily be extracted by means of shaking tables of the Pinder, Wilfley, Woodbury, or Deister type, but it is doubtful whether very much can be taken out by other means, certainly not by sluice boxes, as you have probably already found."

Four additional samples of gold-bearing gravel at the Bailey Creek mining camp were furnished through the kindness of Mr. Davis. Concerning these samples Mr. Day reports:

"The samples of black sand collected from the Snake River gravel at Bailey Creek mining camp, Davis diggings, Lincoln County, Wyo., have been carefully tested and examined.

"Sample No. 5 (our No. 1133), reported 'to be an average sample of the pay streak from the bottom to the top, 20 feet in depth,' gave on assaying:

	Ounces per ton.
Gold	35.64
Silver	4.25
Platinum	None.

"Sample No. 6 (our No. 1134), reported to be 'concentrates of sample 5, from which all gold has been extracted by the churn process,' weighed 137 grams and was run over the Wetherill magnetic separator, giving the following results:

	Grams.
Magnetite	57
Ilmenite	48½
Garnet	12½
Garnet and olivine	5
Tailings (consisting of three-fourths zircon and one-fourth quartz)	19

"An assay gave the following results:

	Ounces per ton.
Gold	8.75
Silver	1.14

"Sample No. 7 (our No. 1135), 'concentrates from which gold has been taken out and concentrates buried for five years,' weighed 101 grams and was run over the Wetherill with the following results:

	Grams.
Magnetite	62
Ilmenite	28
Garnet	9
Olivine	5
Tailings (consisting principally of zircon with some garnet)	14

"An assay gave the following results:

	Ounces per ton.
Gold	29.98
Silver	1.15

"Sample No. 8 (our No. 1136) 'is a sample of pay streak showing gold content.' This gave on assaying:

	Ounces per ton.
Gold	107.41
Silver	10.56
Platinum	4.54"

PINE BAR (No. 3).

Schultz [1] gives the following information concerning Pine Bar:

The terrace at the mouth of Pine Creek, on the south fork of Snake River, has been worked * * * by Ivan L. Hoffer and L. M. Rosencrans. The terrace or old bar at this point is 1 mile long, one-twelfth to one-eighth mile wide, and from 40 to 50 feet above the water level of Snake River. * * *. Water for hydraulicking is brought from a point some distance up Pine Creek in a ditch across the bench. The water is used to break down the gravel, wash out the gold, and sluice through the flume. * * *

[1] Schultz, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: U. S. Geol. Survey Bull. 315, pp. 78-79, 1907; Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 127-128, 1914.

Mr. Hoffer informed the writer that on this bar there is about 8 feet of overlying gravel that contains about 15 very fine colors to the cubic foot, followed by 32 feet of gold-bearing gravel to water level, without striking bedrock. So far only the upper 12 feet of this gold-bearing gravel, which is supposed to be better than that lower down, has been worked.

The following figures, furnished by Mr. Hoffer, give the run of gold in colors for the first 12 feet of gravel in two different places.

Colors of gold in upper gravel at Pine Bar diggings.

Depth in feet.	Colors per cubic foot.	
	A.	B.
1	7,200	6,300
2	23,400	3,600
3	8,100	16,200
4	106,200	11,700
5	8,100	11,700
6	22,500	4,500
7	3,600	5,400
8	17,100	900
	196,200	60,300

The tests were made on one-thirtieth cubic foot of gravel carefully measured and the results per cubic foot were obtained by multiplying these values by 30. About 1,000 to 1,200 colors make 1 cent value. Thus it will be observed that this 8 feet of gravel, both tests being averaged, yields from 12 to 14 cents a cubic yard. Including the upper 8 feet, the value for 16-foot depth averages about 7 cents a cubic yard. Working to a depth of 20 feet or more should slightly raise this value. In a few places small streaks running up to $2 a cubic yard have been cut. Most of these streaks occur on top of the gold gravel immediately below the overlying 8 feet of comparatively barren material.

WELCH GROUND AND GOLD POINT (Nos. 6 and 7).

At the Welch placer, about 1½ miles north of the mouth of Blackfoot River, Snake River has cut into a bank of gravel about 18 feet high, over which there is 2 to 4 feet of fertile sandy loam. The gravels contain gold throughout the depth exposed by the river cut, but those containing the most gold are usually cemented with lime and are composed of smaller pebbles than the great bulk of the gravels. The richer gravels occur in lenses and streaks irregularly distributed in the bank. This deposit is said to average about 40 cents a yard throughout. About 20 acres of gravel next to Snake River has been washed to depths varying from 4 to 12 feet. A ditch about 1,500 feet back from and parallel to the bank furnishes water. The gravels are caved by allowing the water to run out of the ditch through gates. The gold was caught in sluices and on burlap tables. This ground has not been worked for a number of years.

The placer gravels west of Snake River at Gold Point and Eagle Bend, which are from three-fourths to a mile above the mouth of Blackfoot River, rest upon basalt. They have been extensively

worked, but, so far as known, not in the last few years. At Gold Point the gravels are said to average 8 feet in depth and are reported to carry about 40 cents a yard throughout. It is said that very rich "dirt" was found in the crevices in the bedrock, and that some of the cemented gravels found in thin lenses carry as much as $2 a yard.

FORT HALL BOTTOMS (No. 8).

The Fort Hall Bottoms cover approximately 30,000 acres along Snake River in Bannock and Bingham counties, extending from Big Butte, at the junction of the Blackfoot and Snake, to the mouth of Portneuf River, a distance of 24 miles, and varying in width from one-fourth of a mile to 7 miles. They are reached from American Falls, Pocatello, Fort Hall Agency, or Blackfoot. At their eastern margin is a bluff which rises from 15 feet at the north end to 100 feet at the south end, to the level terrace upon which stand Fort Hall Agency and Pocatello. The bottoms have an average elevation of 8 to 10 feet above the normal water level of Snake River. Water stands from 2 feet below the surface at the north end of the bottoms to 9 feet below at the south end. This level is slightly higher than the normal water level of Snake River.

By far the most extensive material found on the surface of the Fort Hall Bottoms is a gray to black sandy loam that in some places contains considerable clay. Gravels occur at the surface in a few places, irregularly distributed over the bottoms. Usually the gravel bars do not cover much more than an acre, but here and there areas of several acres are underlain by gravel. There are more numerous and larger gravel bars within half a mile of the river than in any other part of the bottoms.

There is no doubt that gravels similar to those along the present channel of Snake River underlie all the Fort Hall Bottoms. The upper limit of the gravels varies considerably in different parts of the bottoms. In some places the gravels extend to the surface; in others the sandy loam extends as much as 2 feet below the level of the stream, or 12 feet below the surface.

From the distribution of the gravels on the bottoms away from the river it is thought that they are the tops of buried bars such as are now found along the present channel of the Snake, and from analogy it is thought that the rich gravels are of rather small extent, corresponding to the skim-bar gravels of the present stream.

Bedrock was not found anywhere in the Fort Hall Bottoms. In some places along the terrace east of the bottoms similar gravels rest on partly consolidated clayey sands that Mansfield [1] has referred to the older Quaternary. It seems possible that the bottoms may

[1] Mansfield, G. R., Geology and phosphate deposits of the Fort Hall Indian Reservation, Idaho: U. S. Geol. Survey Bull. (in preparation).

have been cut from similar material and that the partly consolidated Quaternary sands will be found to constitute the bedrock, rather than basalt. At many places west of this part of Snake River basalt flows form the banks. These flows are relatively thin, and it is the opinion of the writer that they originated in the plains west of Snake River and never extended much farther east than their present limit. It seems possible that the course of the Snake in this locality was in large part determined by a shallow depression between the edge of the basalt flow and the gravels and silts upon which the flow rested. In the wells of the high bench[1] in the vicinity of Fort Hall Agency, which reach below the level of the bottoms, nothing but unconsolidated or partly consolidated sand and gravel was encountered above a depth of 75 feet, but at that level there is a 10-foot bed of volcanic rock interbedded with gravels. This flow has a strong dip to the west and would probably be found at a considerable depth if it extends under the bottoms.

The gravels of the Fort Hall Bottoms average less than 1 cent to the yard in gold. The skim-bar gravels, which have been worked each year after high water, carry at least 65 cents a yard in fine gold and perhaps as much as $2 to $3 a yard. The skim bars, however, form a very minor part of the total amount of the gravels of the Fort Hall Bottoms.

HORSE ISLAND (No. 9).

On Horse Island, which is really a continuation of the Fort Hall Bottoms, considerable placer mining has been done in the past, but in recent years the gravels have not received much attention. The surface of this island is from 6 to 10 feet above the normal water level of Snake River. The soil is from 2 to 8 feet thick and rests upon gravels. The gravels that have been worked are near the surface and are for the most part coarse, though some skim-bar gravels are exposed in cuts.

Rockers were used in working most of these gravels, though some on the Elliott ground, at the north end of the island, were worked in a "machine." Horse-drawn scrapers were used to remove the soil and at the machine settings to bring the gravels from the pit to the sluice.

Apparently the pay gravels follow more or less well-defined lines or bars which have a somewhat crescentic shape and are the tops of old high-water bars such as are deposited in the present stream channel.

[1] Heroy, W. B., oral communication.

MINIDOKA.

According to Schultz[1]—

The Government dam at Minidoka has raised the water over an adjacent high terrace that represents an old river bed and contains some of the best values in fine gold along Snake River. This terrace is known as Diamond Bar, and the shallow water now covering it affords a pond with sufficient water to float a chain-bucket or suction dredge, either one of which is adapted for treating this ground. * * *

In May and June, 1906, before the water was ponded above the dam, some prospecting on these gravels was done by the United States Geological Survey. The land examined by L. G. Gillette and W. L. Walker consisted of certain claims along Snake River in Idaho which would be submerged when the lake formed by the dam at Minidoka was full. The claim farthest upstream that was examined was the Golden Treasure, about 25 miles above the dam. The bulk of the work was done in the neighborhood of the old placers in order to determine the value of the ground that was formerly considered profitable. It was found that the values were very irregularly distributed and in but few places equal to the claims made by those interested in the land. The prospecting was accomplished by means of test pits, panning, and sampling, the samples taken being shipped to Portland, Oreg., where they were treated and assayed by the Survey in connection with the black-sand investigation. * * * It was found that in general the values were concentrated in the bottom of the loam and the upper portion of the underlying gravels. The surface soil or sandy loam is common and ranges in thickness from 2 to 12 feet or more. The gold was everywhere of the finest flourlike particles, a large percentage of which would pass trhough a 150-mesh screen. The rocks are in general much smaller than a man's head, although in a few places rocks large enough to interfere with dredging or other mining operations were encountered. * * *

No other minerals of any commercial importance were found. No platinum or monazite was observed and only a trace of zircon. The richest sample contained only 4 pounds of magnetite per ton. These results indicate that the percussion type of machine can be used advantageously in separating the Snake River fine gold from the loam and gravels, especially after preliminary concentration in ordinary sluice boxes and shunting the concentrates onto the tables by means of undercurrents. In the 25-mile stretch examined by Messrs. Gillette and Walker mining work was carried on only at the Sample placer claim, owned by W. H. Philbrick, who employed one stream in his ground-sluicing operations.

NEELY (No. 10).

Schultz[2] gives the following description:

The gravels along Snake River in the vicinity [south and east] of Wapi, Idaho, have been worked by Dunn & Hand, all of their workings being on old high bars or terraces (part of which are now under water) along the present river channel. C. H. Hand states that the gold here is a very fine flake gold and amalgamates readily. The gold is scattered through the gravel but is usually best at the top of the beds. It occurs in heaviest particles in the oldest bars. The pay streaks run from a few inches to 6 or 7 feet in depth but in some places exceed 22 feet, at which depth the gold has run as high as 22 cents per cubic yard. Where bedrock lies at the shallow depths, say from 6 to 8 feet below the surface, the pay streak in some places rests on the bedrock. Occasionally two or more pay streaks are encountered, one on bedrock and the other higher in the gravels or near the top. It is, however, exceptional to find the

[1] Schultz, A. R., Gold developments in central Uinta County, Wyo., and at other points on Snake River: U. S. Geol. Survey Bull. 315, pp. 81-85, 1907.

[2] Idem., p. 86.

pay streak on bedrock. The bars in this locality are very extensive, amounting to hundreds of acres. Actual clean-up, by sluicing some thousand of yards, shows a value of a little more than 20 cents per cubic yard for some million of yards. Gravels of much higher grade occur at some places in thin seams. For a short distance these may run as high as several dollars per cubic yard. The above averages are, however, for gravels worked from 12 to 15 feet in depth and include both the gravels and the surface soil. Besides the gold, the gravels for the above depths carry about three-fourths of 1 per cent of black sand and other heavy minerals.

SOURCE OF THE GOLD.

There can be little question that the fine gold of the Snake was derived from the destruction of older auriferous deposits and not, as suggested by Turner,[1] by precipitation of the gold from the waters of a Miocene lake. That most of the gold above Boise River has come from the Teton, Gros Ventre, Salt River, and Caribou mountains is fairly well established, inasmuch as no gold has been found in Henrys Fork, Blackfoot River, or Portneuf River. It has long been known that in the upper part of Snake River, which heads in the Jackson Hole country, the gravels contain gold. The ultimate source of the gold is not yet definitely known. Some gold has undoubtedly reached the Snake from the Caribou district, of southeastern Bonneville County. The gold-bearing veins and gravels of this district were known as early as 1870 and reported by St. John[2] to be nearly vertical northwestward, trending lodes consisting of rotten ferruginous quartz. Schultz[3] visited the Caribou district in 1913 and reported that while there was considerable gravel in this region, there was only sufficient water to operate for three months each year.

Schultz[4] reports that gold occurs in Jurassic shales, limestones, and sandstones in the northern part of the Wyoming Range at Horse Creek. The sediments are slightly brecciated and contain numerous small calcite seams, and some of them show considerable pyrite. He also reports that fine gold occurs in the Aspen formation, of Upper Cretaceous age. Rocks of the same age are seen along Snake River east and north from Greys River and probably form a considerable part of the Gros Ventre Mountains.

The Teton Mountains, according to Bradley,[5] are composed of a pre-Cambrian core consisting of granite, schist, and gneiss, resting upon which are Paleozoic quartzites and limestones. He noted quartz veins in the granitic core but stated that in general they appear to be barren.

[1] Bell, R. N., The origin of the fine gold of Snake River: Eng. and Min. Jour., vol. 73, pp. 143-144, 1902.

[2] St. John, Orestes, U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pt. 1, pp. 404-405, 1879.

[3] Schultz, A. R., and Richards, R. W., A geologic reconnaissance of southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267-283, 1913.

[4] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 121-122, 1914.

[5] Bradley, F. H., U. S. Geol. Survey Terr. Sixth Ann. Rept., pp. 250-271, 1873.

At the headwaters of Snake River, on Big Game Ridge, there are heavy beds of ferruginous conglomerates which have been named Pinyon conglomerate.[1] In speaking of this conglomerate the authors say:

> For many years gravels along Snake River and Pacific Creek in the neighborhood of Jackson Lake have been known to yield a slight amount of gold * * * but not in remunerative quantities. Evidences of gold may be found * * * in the streams coming down from the conglomerate. It is quite likely that this gold has in great part been derived from the conglomerate of the (Eocene) Pinyon formation.

Shockley,[2] who examined the gold gravels of the Jackson Hole country, came to the conclusion that the gold was derived from the decomposition of auriferous pyrite, which he found in bowlders of andesitic rocks.

CONCLUSION.

While it is true that practically all the gravels of the Snake River valley contain gold, it seems to be equally true that most of the deposits contain so little gold that they can not be called placers. There is little question that some small deposits contain sufficient gold to pay for extraction if it were possible to work them on a large scale, and it is probably true that a few relatively small gravel deposits contain sufficient gold to be worked at a profit by hand methods.

The problem of saving the fine gold is one which has received much attention. None of the methods so far tried has proved entirely efficient or commercially successful. Perhaps the solution of this problem may be in the direction of the cyanide process, though much experimenting must be done before a commercially profitable development of this sort can be hoped for.

Under the present conditions of distribution, character of the gold, and methods of its recovery, it seems very doubtful if any ventures of a size large enough to expect success can be commercially profitable.

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[1] Iddings, J. P., Weed, W. H., and Hague, Arnold, Geology of the Yellowstone National Park: U. S. Geol. Survey Mon. 32, pt. 2, pp. 184, 185, 189, and atlas, 1899.

[2] Shockley, J. H., The origin of the fine gold in Snake River, Idaho: Eng. and Min. Jour., vol. 73, pp. 280-281, 1902.

PRELIMINARY REPORT ON THE ECONOMIC GEOLOGY OF GILPIN COUNTY, COLORADO.

By Edson S. Bastin and James M. Hill.[1]

INTRODUCTION.

The following brief account of the economic geology of Gilpin County and adjacent portions of Clear Creek and Boulder counties, Colo., summarizes the more important results of an exhaustive geologic study of the region. The final report, which will appear as a professional paper of the United States Geological Survey, is voluminous, and as its publication will consume much time it appears desirable to publish this summary to meet in part the numerous demands for information concerning this important mining district.

The area considered lies 30 to 35 miles west and northwest of Denver, in the heart of the Front Range of the Rocky Mountains. It is the oldest lode-mining region in Colorado, and its discovery in 1859 was the occasion of a "rush" second only in magnitude and consequences to that caused by the California discoveries of 1849. The area includes the productive portions of Gilpin County and small adjacent parts of Boulder and Clear Creek counties, all within the regions shown on the Central City topographic sheet of the United States Geological Survey. The country is mountainous and of moderate humidity. The principal mining centers are, in Gilpin County, Central City, Blackhawk, Nevadaville, Russell Gulch, Perigo, and Apex; in Clear Creek County, Idaho Springs, Gilson, Alice, Dumont, and Lawson; in Boulder County, Caribou and Eldora.

GENERAL GEOLOGY.

The entire area is underlain by the body of pre-Cambrian rocks that forms the core of the Front Range. Probably in early Tertiary time igneous rocks of many varieties were intruded as dikes or stocks into the pre-Cambrian rocks; these intrusives are the "porphyries" of the miners. Surface deposits formed by glaciers or streams are the only other formations present.

[1] Mr. Charles W. Henderson assisted in a part of the field work.

PRE-CAMBRIAN ROCKS.

The essential characters of the pre-Cambrian formations are shown in tabular form below, the youngest at the top, the oldest below:

Pre-Cambrian rocks of Central City quadrangle, Colo.

Igneous rocks.	*Silver Plume granite:* Medium-grained biotite granite with coarser pegmatitic facies.	Little or not at all dynamometamorphosed.
	Quartz diorite: Medium grained, locally grading into hornblendite.	
	Granite gneiss: Fine to medium grained, somewhat gneissic granite with coarse-grained pegmatitic facies.	Moderately dynamometamorphosed.
Sedimentary rocks.	*Idaho Springs formation:* Mostly quartz-biotite and biotite-sillimanite schist, with some hornblende schist and lime-silicate rock.	Highly dynamometamorphosed.

The more important characteristics of these formations are briefly described below.

IDAHO SPRINGS FORMATION.

The Idaho Springs formation, first defined by Ball,[1] underlies fully half of the eastern portion of the Central City quadrangle. It is also widely distributed to the east, in the Blackhawk quadrangle, and to the south, in the Georgetown quadrangle. As its commoner rock types are somewhat less resistant to erosion than most other rocks of the region it forms few high peaks or ridges, and for this reason it is a fair inference that the formation is not so widespread in the high western portion of the quadrangle, not here mapped, as in the eastern portion.

Over certain areas, as for example between Nevadaville and Mount Pisgah, the formation is rather free from intrusive igneous rocks; but in most localities igneous rocks are associated with it in great abundance and in very intimate and irregular fashion.

The predominant rocks of the Idaho Springs formation are light to dark gray quartz-biotite schists, in places carrying some hornblende or muscovite. With these are associated lesser amounts of biotite-sillimanite schist, quartzitic gneiss, dark-green hornblende schist and gneiss, and lime-silicate rocks that represent metamorphosed limestones, and in a few places rocks that are supposed to be metamorphosed conglomerates are found. These rocks are interbanded, show transitional varieties, and are clearly integral parts of one formation. The less common types occur mostly as lens-shaped

[1] Ball, S. H., Geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 63, p. 37, 1908.

masses and not as continuous bands that might serve as indicators of structure.

Throughout most of the formation bedding planes have been entirely obliterated by the development of schistose structure, the biotite and biotite-sillimanite schists in particular being highly foliated. On the other hand, certain bands of quartzitic schist that in some places persist with fairly uniform width for several hundred feet are interpreted to represent beds, originally more sandy than their neighbors, that have retained in part their original form because the constituents for the development of platy minerals during metamorphism were scarce.

The general strike of the foliation is, in some parts of the quadrangle, fairly uniform over a number of square miles, but in most places the schists have been so disturbed by numerous intrusions of igneous rocks that all conceivable inclinations can be observed within a single square mile, and faulting has produced further irregularities. The foliation exhibits no broad parallelism with the axis of the range.

The Idaho Springs schists and lime-silicate rocks are believed to have been formed by the general dynamic metamorphism and local igneous metamorphism of a thick series of sedimentary rocks.

GRANITE GNEISS.

The granite gneisses of this area have acquired a gneissic structure through dynamic metamorphism. Their essential minerals, like those of the massive granites, are quartz, alkali feldspar, and either muscovite or biotite.

The granite gneiss is comparatively rare in the northern part of the area mapped but underlies nearly half of the central and southern portions. Its areas, though of irregular outline, are commonly elongate in a northeasterly direction, parallel to the dominant trend of the inclosing Idaho Springs schists. Some areas are 4 to 5 miles long and 2 to 3 miles across, but most of these large masses inclose small areas of the Idaho Springs formation. Excellent exposures of the granite gneiss are numerous on the surface and in the mines near Central City and along the lower course of Fall River.

The granite gneiss is believed to be a granitic intrusive rock that has received a foliated structure as a result of dynamic metamorphism subsequent to its intrusion. Its intrusive character is attested by occasional offshoots from the gneiss masses that penetrate the Idaho Springs schists, transgressing their foliation, by angular schist fragments inclosed by the granite gneiss, and by contact-metamorphic effects produced in rocks of the Idaho Springs formation inclosed by or bordering on masses of granite gneiss.

The granite gneiss is a part of the pre-Cambrian axis of the Front Range. Its structural relations and its degree of metamorphism indicate that it is intermediate in age between the oldest and the youngest of the pre-Cambrian rocks. It is distinctly younger than the oldest pre-Cambrian formation, the Idaho Springs formation, which it intrudes. It is evident, moreover, that the Idaho Springs formation was schistose prior to the intrusion of the granite gneiss magma and that the magma in many places followed this schistosity as the direction of easiest intrusion. At least one important period of dynamic metamorphism intervened, therefore, between the deposition of the sediments of the Idaho Springs formation and the intrusion of the granite gneiss magma. On the other hand, the granite gneiss is itself intruded by granite pegmatite and massive granite of later age.

QUARTZ DIORITE AND ASSOCIATED HORNBLENDITE.

Massive to slightly gneissic coarse-grained rocks varying from quartz diorites to hornblendites in mineral composition are found principally in the central and southern parts of the area surveyed. The largest body extends from a point 1¼ miles east of Yankee northeastward to Montana Mountain and Pine Creek, and its width for most of this distance is nearly half a mile. Most of the other bodies form broad dikes whose trend is northeast, parallel to the prevailing trend of the foliation in the inclosing schists and gneisses. In the northern part of the area surveyed quartz diorite has been noted only in two small patches north of Nederland.

The quartz diorite and its associated lighter and darker colored rocks are intrusive igneous rocks, probably of pre-Cambrian age. They were intruded subsequent to the development of most of the foliation in the Idaho Springs formation but before the intrusion of the Silver Plume granite and its associated pegmatite. The relation of the quartz diorite to the granite gneiss, though far from clear, suggests that the two rocks are of nearly the same age and possibly came from a common magmatic source. An alternative hypothesis, suggested by Ball,[1] is that the quartz diorites and hornblendites are derived from the same magmatic source as certain pre-Cambrian quartz monzonites that occupy large areas in the Georgetown quadrangle but are not exposed within the surveyed parts of the Central City quadrangle.

GRANITE PEGMATITE.

Under the name granite pegmatite are included rocks of coarse and usually irregular texture, containing the same minerals that are found in normal granites. The principal constituents are potash feldspar,

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[1] Ball, S. H., op. cit., p. 56.

quartz, biotite, and muscovite, but many other minerals are present in subordinate amounts.

Granite pegmatite in masses too small to map is abundant throughout most of the area mapped as Idaho Springs formation. Most of these small intrusions have the form of long, narrow lenses, or pinching and swelling dikes, lying parallel to the foliation of the schists or cutting the foliation at small angles. Other pegmatite masses are exceedingly irregular and may transect the schist foliation in various directions and even inclose angular fragments of schist. In many places the pegmatite magma penetrated the schist so intimately that pegmatite and schist form an injection gneiss, and locally isolated "eyes" of pegmatite were developed; these show no evidence of strain and can not be regarded as pegmatite fragments isolated as a result of shearing.

The granite pegmatites of the Central City quadrangle are believed to have been derived in part from the granite gneiss magma and in part from the Silver Plume granite magma. As the pegmatites derived from each source are similar in mineral character it is possible to distinguish them only in the relatively few places where they can be traced into bodies of granite gneiss or granite. The relative importance of the two magmas as sources of pegmatites can not be estimated, but it seems probable from the areal distribution of granite gneiss and granite that the pegmatite of the southeastern part of the quadrangle came mainly from the granite gneiss magma and that of the northeast part of the quadrangle came mainly from the Silver Plume granite magma. As already stated, the granite gneiss and the Silver Plume granite, though probably of widely diverse ages, are both believed to be pre-Cambrian. So far as observed, the Tertiary (?) "porphyry" magmas yielded no pegmatitic rocks.

SILVER PLUME GRANITE.

The name Silver Plume granite was applied by Ball to a medium-grained, usually porphyritic biotite granite forming numerous stocks and dikes in the vicinity of Silver Plume and Georgetown. In the present report all the granite of the quadrangle that is distinctly younger than the granite gneiss is classed under this heading, although there is some question whether all of it is the precise equivalent of the granite of the type locality near Silver Plume.

The Silver Plume granite is widely distributed through all except the southeastern portion of the quadrangle. It forms irregular stocks, commonly more or less elongate parallel to the prevailing trend of the foliation in the schist of the Idaho Springs formation or the granite gneiss. The largest body, just northeast of Caribou, is about 3 miles across.

The Silver Plume granite is intrusive into most of the pre-Cambrian rocks of the quadrangle. The only rocks observed to cut the granite are the "porphyries," of probable Tertiary age, and a few dikes of pegmatite which probably came from the same magmatic source as the granite itself. The Silver Plume granite is believed to be pre-Cambrian, and with the exception of its own pegmatitic phases it is the youngest of the pre-Cambrian rocks of the quadrangle. The possibility of a Paleozoic age for this granite can not be excluded on the basis of any evidence found within this quadrangle, but where Paleozoic rocks are exposed on the flanks of the Front Range no granites intrusive in them have been noted.

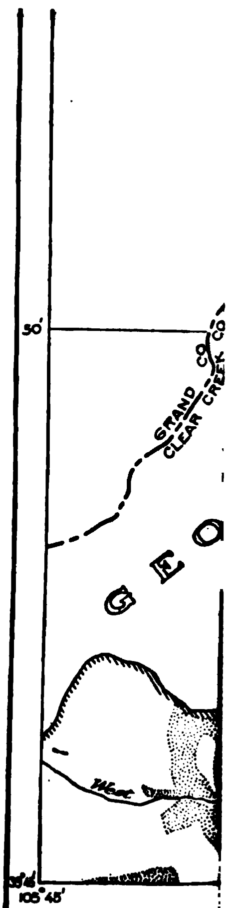
TERTIARY (?) INTRUSIVE ROCKS.

PRINCIPAL TYPES.

Throughout all parts of the area surveyed igneous rocks, intrusive in the pre-Cambrian formations, are of common occurrence. These intrusives constitute irregular stocks and dikes, whose form and distribution are shown on Plate IX. The commonest rock types are monzonites and related quartz monzonites, in large part of porphyritic texture. These rocks make up practically the whole mass of the larger stocks and many of the dikes, and in quantity they far exceed all other types among the Tertiary (?) intrusives. The remaining types occur as dikes and small stocks and lenses and to a lesser extent as irregular masses within monzonite stocks. The best examples of these irregular masses are the titaniferous iron ores and associated gabbros, peridotites, etc., near Caribou, which are clearly differentiation products within a monzonite magma. The dikes and small stocks and lenses are represented by the bostonites of the southern part of the quadrangle and the andesites, diorites, and basalts of the northeastern part of the quadrangle. Although many of these dike rocks differ greatly in mineral character from the quartz monzonites, it is thought probable that most of them had a common magmatic source and are of essentially the same age. Their differences are attributed to magmatic differentiation at considerable depth prior to intrusion into their present positions.

As the monzonitic rocks constitute most of the stocks as well as many of the dikes, their total volume is many times the combined volume of all other types. It is probable, therefore, that the parent magma from which the various rock types were derived, through differentiation, had very nearly the average composition of the large monzonite stocks.

The two most abundant types among the Tertiary intrusives may be briefly described. Their distribution is shown on Plate IX.



SKETCH MAP OF

QUARTZ MONZONITE AND QUARTZ MONZONITE PORPHYRY.

The quartz monzonites of the Central City quadrangle contain orthoclase feldspar, calcic plagioclase feldspar, some quartz, and usually some iron-bearing minerals. There are great variations in the proportions of the minerals, in the coarseness of the grains, and in the degree to which phenocrysts are developed. In many localities iron-bearing minerals are not conspicuous, but in certain places they may be present in amounts up to 30 or 40 per cent by volume and give to the rock a dark-gray color. In the porphyritic varieties the phenocrysts may be wholly feldspar, or there may also be phenocrysts of quartz or of iron-bearing minerals. The phenocrysts may be small or large, ranging from 1 millimeter to 3 centimeters, and may be all of the same order of magnitude or of heterogeneous sizes. The groundmass appears structureless (aphanitic) to the unaided eye and in fresh specimens is light gray to purplish gray. In the nonporphyritic varieties the texture may approach porphyritic (porphyroid) or, more rarely, may be rather evenly granular. A few dikes are coarsely porphyritic at the center and more finely porphyritic or massive at their borders. Many varieties are usually present within the same monzonite stock, and even a single narrow dike may show considerable variations in character along its length. The monzonites are usually massive; only in a few places do they show a slight banding attributable to flowing movements during crystallization.

Quartz monzonites and monzonite porphyries are present in nearly all parts of the area surveyed. The largest masses are the stocks near Apex, Ute Mountain, and Caribou. Dikes are particularly abundant in the vicinity of Idaho Springs. The details of distribution are fully shown on the map (Pl. IX).

BOSTONITE AND BOSTONITE PORPHYRY.

The bostonites of the Central City quadrangle are gray to lilac-colored or reddish-brown, very fine grained (microcrystalline) rocks, composed predominantly of alkali feldspar with only small amounts of quartz. Varieties with phenocrysts of alkali or alkali-calcic feldspar or of pyroxene, or both, are termed bostonite porphyry. The bostonites and bostonite porphyries are confined mainly to those parts of the surveyed area lying southeast of Mammoth Gulch and east of Empire. They occur mainly as dikes, which in a few places expand into lens-shaped masses one-eighth of a mile or so across. Some of the dikes are of extraordinary lengths, one being traceable continuously from the Topeka mine, near Russell Gulch, northwestward for 4½ miles. The distribution of the bostonite dikes between the camps of Russell Gulch and Nevadaville is noteworthy, for they

radiate from a small bostonite area near the Topeka mine. Expansions of the dikes into narrow stocks occur 1 mile southeast of Dumont and 1½ miles north of Lawson.

Though the bostonite porphyries are not always distinguishable without microscopic study from certain monzonite porphyries, most of them can be readily recognized because of their pinkish, lilac, or reddish-brown body or groundmass through which are scattered pearl-gray or salmon-colored phenocrysts of feldspar, commonly under 5 millimeters in length, though occasionally as long as 1 or even 2 centimeters. Some varieties contain green prisms of pyroxene or its alteration products as much as 5 millimeters in length.

The pyroxene-free bostonite porphyries are not readily differentiated, without the aid of the microscope, from certain monzonite porphyries of the region between Apex, Perigo, and Phoenix, which have a pinkish groundmass, but microscopic examination of the monzonites shows that the groundmass is granular rather than trachytic, as in the bostonites. In most of the bostonite porphyries the phenocrysts are widely scattered, and many of them show rhombic outlines. The nonporphyritic bostonites, if fresh, are usually recognizable by their lilac or reddish-brown color, but if altered by surface weathering or by mineralizing solution they are usually bleached buff and can not then be distinguished, without microscopic examination, from fine-grained monzonites.

OTHER TERTIARY (?) INTRUSIVE ROCKS.

In the vicinity of Caribou there occur within monzonite stocks small bodies of dark-colored rocks, including iron ores, which have clearly formed by processes of differentiation from the monzonite magma. These rocks are further mentioned on page 313 in the discussion of the titaniferous iron ores.

The region between Caribou, Nederland, and Phoenix is characterized by the presence of a profusion of dikes, having a prevailing easterly trend, of types not found elsewhere in the quadrangle. They include hornblende monzonite porphyries, hornblende and biotite andesites, and hornblende and biotite diorites. Many of the diorites are very dark. These various dikes are not wholly contemporaneous, for at a number of places diorite dikes were observed to cut those of andesite. Nevertheless, it seems probable that the age differences are not very great and that all types were derived from a common parent magma of monzonitic composition. These dikes appear to take the place, in the Nederland region, of the monzonite dikes so common in other parts of the quadrangle.

The geologic relations within the Central City and Georgetown quadrangles indicate merely that the "porphyries" are younger than the pre-Cambrian rocks, which they cut, and are, with a very few

exceptions, older than the ore deposits. In neighboring parts of Colorado, however, similar "porphyries" are in contact with sediments of determinable age. The evidence from these adjacent districts points to a Tertiary age for these intrusive rocks.

STRUCTURE.

The most important structural characteristic of the region is the intricate manner in which the igneous rocks, ranging from pre-Cambrian to Tertiary (?) in age, have been intruded into the sedimentary Idaho Springs formation and into each other. The intrusives range in size from mere threads between schist folia to stocks several miles across. Dikes are particularly abundant, and a few of them are traceable continuously for over 5 miles. Many of the intrusives are lenticular in form, with their greatest dimensions parallel to the prevailing foliation of the inclosing rocks; others are extremely irregular.

Purely dynamic processes have also played a part in the structural history, their principal effect being the development at great depths of foliation in the older pre-Cambrian rocks. During much later periods at shallower depths faulting took place. Some of the faults were formed prior to or contemporaneous with the intrusion of the Tertiary igneous rocks; others were formed soon after these intrusions and became the sites of ore deposition; and still others were formed subsequent to the mineralization and displaced the ore bodies. Faulting may still be in progress. Joints are numerous in the more rigid rocks and commonly parallel one or more of the directions of faulting.

ECONOMIC GEOLOGY.

ORES GROUPED BY PREDOMINANT METAL VALUES.

The ores of Gilpin County and adjacent areas here described may be grouped, according to the metals which give them their predominant value, into five classes—(1) gold-silver ores, which constitute the main economic resource of the region; (2) uranium ores, highly localized but of much interest as a source of radium; (3) tungsten ores, which form the basis of the tungsten industry of Boulder County, the largest producing center for this metal in the United States; (4) copper ores, poor in precious metals, represented solely by the Evergreen mine, near Apex; (5) titaniferous iron ores of Caribou, Boulder County, which are not commercially valuable.

The region forms part of a broad mineralized belt embracing most of the important mining camps of Colorado.

ORE STRUCTURE.

Veins far exceed in abundance and importance all other structural types among the ore deposits of this region. A few large deposits

are stockworks, and there are also a few irregular ore bodies formed by magmatic differentiation. Mechanical concentrations are represented by auriferous gravels, now practically worked out.

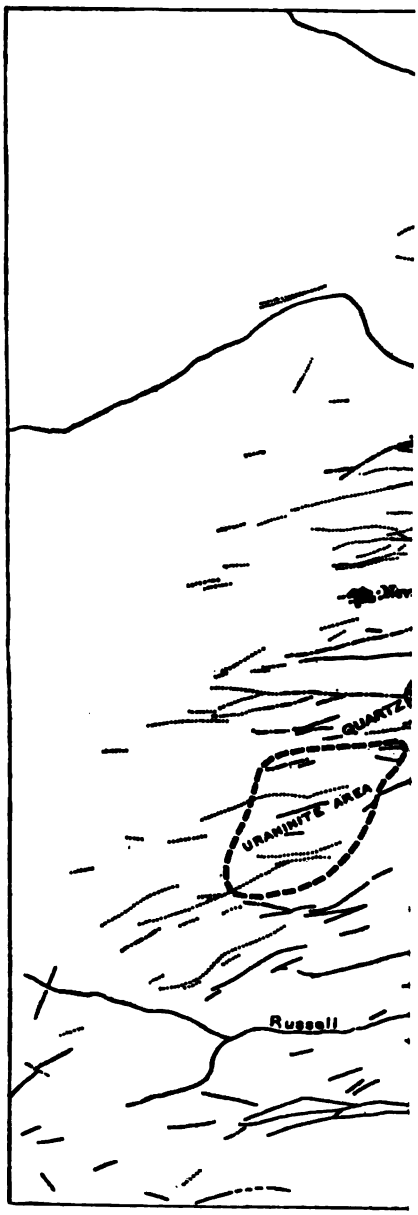
Veins.—Most of the ore bodies occupy zones of minor faulting and are true veins. These commonly strike between east and N. 45° E., and dip at angles of 60° or more; "flat" veins are rare. Their width is commonly between 1 foot and 5 feet, but telluride-bearing veins as narrow as half an inch or less are worked, and exceptional mineralized zones attain a width of 40 feet. A very few veins are fillings of a single persistent fracture, but most of them are mineralized fracture zones. In many of these zones brecciation has occurred and the spaces between the rock fragments have been filled with metallic minerals. The longest vein noted is the Mammoth, near Central City, which is traceable on the surface almost continuously for 6,000 feet. Few other veins attain half this length. The greatest depth to which a vein has been followed is 2,250 feet along the dip, in the California. While certain veins are without important branches, most of them are elements of a complicated vein network composed of master veins connected by oblique cross veins.

Mineralization along the vein fractures was accomplished by the filling of open spaces and by solution of the rocks and deposition of ore minerals in their place (replacement). In most veins both processes were operative, but their relative importance differs in different veins and in different parts of the same vein. On the whole, replacement has been more important than fissure filling.

Stockworks.—One of the most interesting geologic features of the region is the so-called Patch on Quartz Hill. (See Pl. X.) The Patch may be described as a roughly cylindrical mass of brecciated rock, which is locally well mineralized. Its surface outcrop is oval and about 500 by 800 feet across, and the breccia has been traced downward in mine workings for about 1,600 feet, and may extend much deeper. The brecciated rocks are pre-Cambrian granite gneiss and Tertiary porphyry (bostonite), so that the brecciation is later than the porphyry intrusion. Movement within the Patch has locally been great enough to mingle indiscriminately rock fragments of several different varieties. The brecciation and also the mineralization have, in general, been greatest along the line of several veins of northeasterly trend that enter at one side of the Patch and emerge at the other. The mineralization of the Patch, as of the veins, has been accomplished in part by the filling of open spaces and in part by replacement.

The origin of this peculiar ore body has been the subject of much speculation among the mining men of the region. Detailed evidence of origin will not be given here, but it is entirely clear that the Patch

U. S. GEOLOGICAL SURVEY



—— Pyritic o

MAP SHOWING

breccia was formed by the same general movements that developed the associated vein fractures. Where the Patch now is a number of strong vein fractures approached unusually close to one another, and the movement along them became distributed throughout the intervening rock. The mineralization of the Patch is continuous with that of the veins that enter it and is of the same mineralogic character.

Mineralized breccias similar to the Patch but less extensive occur in the Hubert mine, at Nevadaville, and the Alice and Commercial Union mines, near Alice.

Magmatic segregations.—Within a monzonite stock at Caribou occur four bodies of gabbro and related rock of somewhat rounded outline. The greatest dimension of any of these is about one-fourth mile. Within these gabbro masses in turn occur several small bodies of titaniferous iron ore, some of which are lens-shaped and others wholly irregular. Gradations are traceable from iron ore through gabbro into monzonite, and the ore was unquestionably formed through magmatic differentiation.

The copper minerals of the Evergreen mine, near Apex, occur within dikes of monzonite, where they crystallized at the same time as the silicates of the rock. The ore is apparently a product of magmatic differentiation under localized and unusual conditions. (See pp. 311–312.)

Auriferous gravels.—The Pleistocene and Recent gravels of this area, originally auriferous, were practically worked out many years ago.

GOLD-SILVER ORES.

GENERAL CHARACTER.

The main dependence of the mining industry of Gilpin County is upon auriferous and argentiferous sulphide veins, with a few stockworks. In some of these deposits copper or lead or, more rarely, zinc are abundant enough to be of supplementary value. In most of them gold greatly predominates in value over silver, but in some, usually as a result of downward enrichment in silver, the reverse is the case. Of less though not inconsiderable value are deposits in which the gold and silver occur mainly as tellurides rather than in sulphides. Gold placers may be neglected in the present discussion.

One of the most interesting features of the ore deposits is the mineralogic diversity exhibited by the sulphide ores of gold and silver. This permits them to be classified as (*a*) pyritic ores; (*b*) galena-sphalerite ores; (*c*) composite ores, carrying the minerals of both the other classes. The distribution of the veins of these three classes in the vicinity of Central City is shown on Plate X.

PYRITIC ORES.

The commonest type of gold ores contains pyrite as the predominant sulphide. Chalcopyrite and tennantite are usually present, but always in subordinate amounts. The principal gangue of the ores that are fissure fillings is quartz, but the gangue of the replacement ores is sericitized wall rock. A group of veins, all lying within three-fourths of a mile of the Hazeltine mine, near Russell Gulch (see Pl. X) differ from the commoner pyritic veins in carrying enargite ($3Cu_2S.As_2S_5$) instead of tennantite ($4Cu_2S.As_2S_3$). Fluorite is a constituent of most of these enargite-bearing veins and of a few neighboring veins of the ordinary pyritic type. The enargite and fluorite bearing veins are believed to be merely local variations of the pyritic mineralization, for both enargite and fluorite are contemporaneously intergrown with the typical minerals of the pyritic ores.

Detailed studies of many ore samples show that the pyritic ores are as a rule irregularly massive in texture, and that the characteristic ore minerals were all deposited during the same period of mineralization. It is possible to recognize among them, however, a prevailing sequence analogous to the order of crystallization among the minerals of a massive igneous rock. To epitomize, chalcopyrite, tennantite, and fluorite were deposited in greater abundance in the later than in the earlier stages of the pyritic mineralization, as shown by their tendency to line vugs or to occupy the medial portions of veins. The chemical significance of the order of crystallization may be summarized in the statement that copper, arsenic, antimony, bismuth, and fluorine were deposited mainly in the late stages of the mineralization, whereas iron, sulphur, and silica were deposited throughout the process.

The pyritic ores are the most widely distributed ore type, occurring in practically all parts of the region under discussion. They constitute the entire output of the Saratoga, Pewabic, Old Town, Alice, and many other mines. The metal content of the smelting ore commonly lies within the following limits: Gold, 1 to 3 ounces to the ton; silver, 4 to 8 ounces to the ton; copper, commonly less than 1.5 per cent, but in some ores 15 to 16 per cent. The gold content is commonly highest in the ores that are richest in chalcopyrite.

GALENA-SPHALERITE ORES.

In the ores of the second type the predominant primary sulphides are galena and sphalerite; pyrite is next in abundance, and then chalcopyrite. The principal gangue minerals, where the ores are fissure fillings, are quartz and either siderite or calcite; where the

ores are replacements the gangue is sericitized wall rock. Like the pyritic ores, these ores occur principally as veins but subordinately as stockworks. In a few veins of this type situated near the head of Gilson Gulch, northeast of Idaho Springs, rhodochrosite is present. Barite is not uncommon as a subordinate gangue mineral. A distinct sequence in the order of crystallization of the minerals of these ores is much less apparent than in the pyritic ores. Most of the constituents appear to be strictly contemporaneous, but in some ores the crystallization period of resin sphalerite, calcite, siderite, or quartz persisted later than that of the other constituents. The ore texture is irregularly massive, rarely crustified.

The metal content of the galena-sphalerite ores is much more variable than that of the pyritic ores. In some of the ores (those of Red Elephant Hill, near Lawson, and Caribou, for example) the gold content is negligible, and the veins are workable for silver only where the silver content has been augmented by downward enrichment. In others (such as the Topeka, Hubert, and Egyptian) workable amounts of gold occur in the primary ores. In general, for the smelting ores of the galena-sphalerite type, the gold content is between 0.1 and 5.5 ounces and the silver content between 2 and 25 ounces to the ton. A noteworthy exception is the remarkable bonanza ore of the Klondike vein in the Topeka mine, near Central City, which carried free gold in extraordinary amounts. An 88-pound piece when smelted yielded $5,449, largely in gold. This gold was a primary crystallization, being contemporaneously intergrown with the characteristic primary sulphides of the vein. The copper content of the galena-sphalerite ores is usually below the commercial limit of 1.5 per cent and rarely exceeds 10 per cent. Lead ranges from a trace to 55 per cent, and zinc from a trace to 25 per cent. In general the primary ores of this class are poorer in gold and copper and richer in silver than those of the pyritic type.

The galena-sphalerite ores, though widely distributed within the area under discussion, are somewhat less common than the pyritic ores. The mining camps, such as Caribou and Lawson, that have grown up near certain groups of these veins, are classed as silver camps because of the great predominance of that metal in their ores.

COMPOSITE ORES.

The ores to which the term composite is here applied are the result of dual mineralization, first with minerals characteristic of the pyritic ores and later with minerals characteristic of the galena-sphalerite ores. Many of the most important mines of the region, such as the Gunnell and California, have produced ores of this

character. Plate XI shows the appearance to the unaided eye and figure 18 the microscopic appearance of typical composite ores. Such relations as are pictured in these illustrations indicate (1) pyritic mineralization, (2) fracturing, and (3) mineralization of the galena-sphalerite type. These relations were noted in many ores in all parts of the region, and it appears certain that they are usual and not exceptional. The reverse relation, of galena-sphalerite ore brecciated and its interspaces filled with pyritic ore, was nowhere noted. In harmony with this relation is the occurrence of minerals characteristic of the galena-sphalerite ore type in vugs in pyritic ore. In many mines two or all of the three types, pyritic, composite, and galena-sphalerite ores may be present. Veins that near the surface are composite very commonly become pyritic at greater depths, and many veins are composite at one end of their outcrop and pyritic at the other.

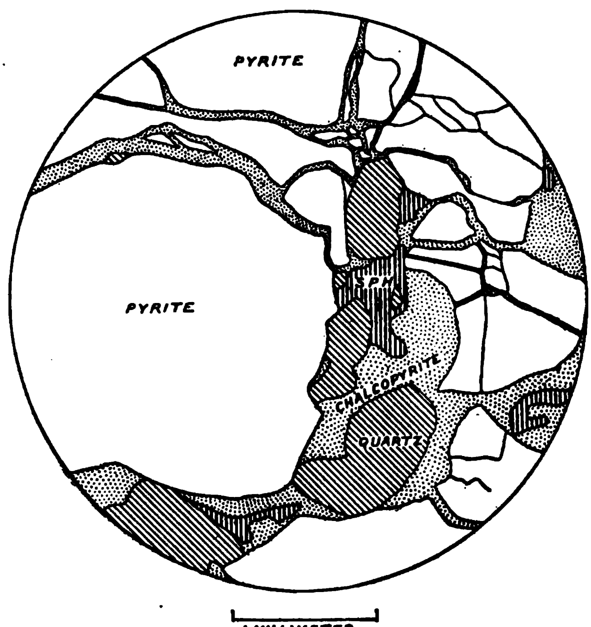
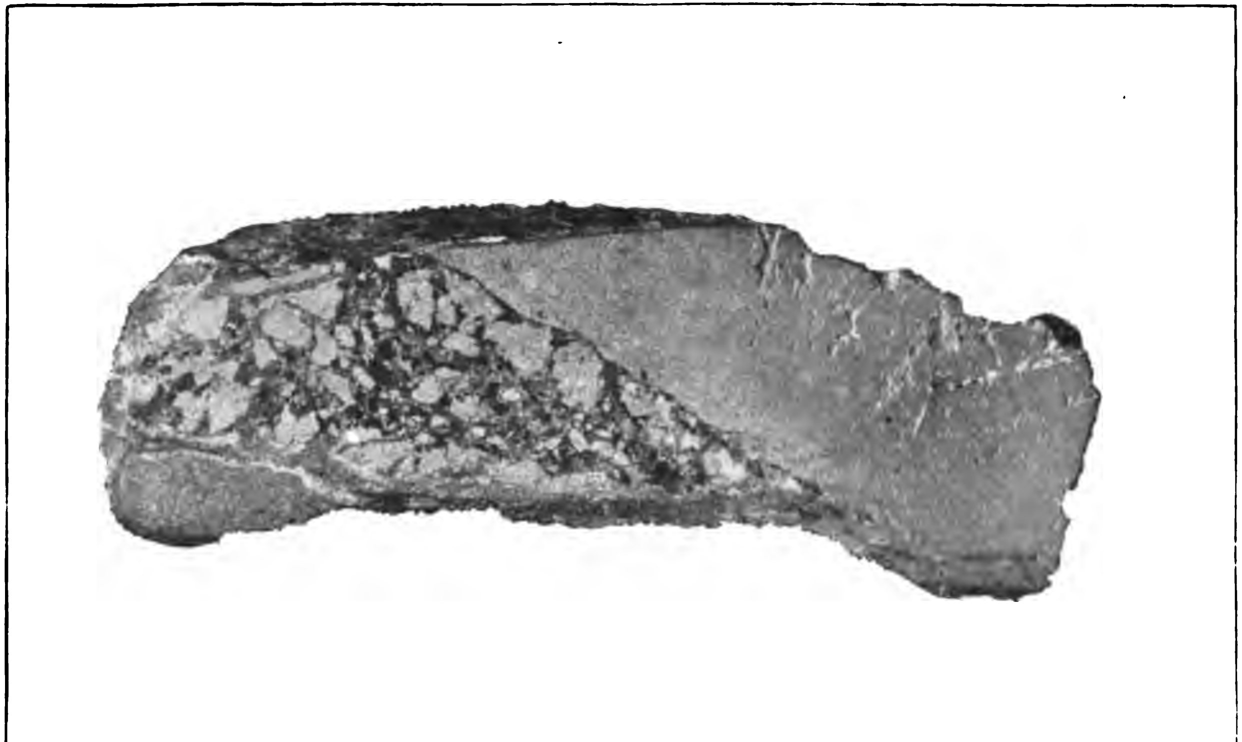


FIGURE 18.—Drawing showing microscopic appearance of polished surface of gold-silver ore from Specie Payment vein, Gilpin County, Colo. SPH, sphalerite.

As would be expected, composite ores are most abundant in the border regions between areas characterized by pyritic ores and areas of galena-sphalerite ores. The metal content of the composite ores is extremely diverse; it has all the variability that characterizes each component type and varies also with the proportions in which the two component types are mingled.

ALTERATIONS OF WALL ROCK NEAR SULPHIDE ORES.

The predominant wall-rock alterations associated with the three types of sulphide ores just described consist of the development of sericite and pyrite. Even near fissure fillings that consist predominantly of galena and sphalerite pyrite is the principal sulphide developed in the walls. Carbonates (usually calcite or siderite)



PHOTOGRAPH OF POLISHED SURFACE OF ORE OF COMPOSITE TYPE FROM FOURTH OF JULY MINE, NEAR CENTRAL CITY, COLO.

Pyritic ore has been brecciated and the fracture openings filled with ore of the galena-sphalerite type. Two-thirds natural size.

are developed near some veins and not near others; they are much more abundant near ores of the galena-sphalerite type than near the pyritic ores. In their early stages the alterations are markedly selective, the minerals showing differing susceptibilities to alteration and yielding different alteration products, thus indicating a chemical interchange between certain rock minerals and the mineralizing solutions. Chlorite and epidote, formed locally in the early stages of alteration, are during a later stage replaced by sericite. The earlier effects of alteration vary in different kinds of rocks, but the final products of the process are similar whatever the original character of the rock.

TELLURIDE ORES.

The telluride ores of the quadrangle show more diversity in mineral character than the sulphide ores of gold and silver, and knowledge concerning them is less definite. It is not certain that all of them were formed at the same time.

Tellurides of gold and silver have been found in close association with sulphide ores of gold and silver in the Gem and Casino mines, near Idaho Springs, and in the Kokomo, Sleepy Hollow, and Gregory mines, near Central City, but the writers were unable to procure specimens that showed the mutual relations of sulphides and tellurides. It is uncertain, therefore, whether the tellurides of such veins were deposited during the sulphide mineralization or represent a separate mineralization. In the mines that have been the largest producers of telluride ores the tellurides, although associated with some sulphides, were not components of typical sulphide ores of the types that have been described but occurred in entirely different mineral associations which will be briefly described. In the East Notaway and West Notaway mines, near Central City, the tellurides occur as a constituent of small veins, characteristically 1 inch to 3 inches wide, which consist mainly of dark-gray fine-grained quartz with minor amounts of fine-grained pyrite and antimoniacal tennantite. Locally there are networks of small veinlets instead of a single vein. Microscopic study shows that all the vein minerals belong to the same period of mineralization, but sulphides are commonly most abundant near the walls of the veins and the telluride is most abundant near the center. The telluride, which is sylvanite, usually forms isolated bladelike or tabular crystals in the quartz, but locally it is contemporaneously intergrown with tennantite. The telluride veins cut dikes of Tertiary monzonite porphyry and cut a typical sulphide vein of the pyritic type (the Homestake).

The most important present producers of telluride ores are the War Dance mine, near Central City, and the Treasure Vault, near Idaho Springs. In both these mines the tellurides are associated

with abundant fluorite and with pyrite, resembling in these respects the ores of Cripple Creek. In the War Dance mine, which afforded the best opportunities for study, the telluride ore forms networks of small veinlets and irregular replacements of the wall rock near minute fractures. The ore minerals are fluorite, quartz, pyrite, and a telluride of gold and silver that is probably sylvanite. The telluride occurs as small flakes or plates of pale brass color, usually inclosed by fluorite. Free gold is present in some of the ores of this type, but as the specimens available were not adapted to microscopic study it could not be determined whether the gold was primary or a product of oxidation. In the War Dance mine a sulphide vein of the composite type occurs close to the telluride ore. This sulphide vein is not known to carry tellurides and is poor in gold. Hence it is probable that the two ore types were not contemporaneous.

Telluride ores of gold and silver occur near Eldora, in Boulder County, but as none of the mines could be entered the writers are unable to add anything to the published descriptions of Rickard[1] and Lindgren.[2]

URANIUM ORES.

Uraninite or pitchblende occurs in nature (*a*) in small amounts in granite pegmatites and (*b*) in intimate association with commoner metallic minerals in a few ore deposits. Quartz Hill, near Central City, is the one important locality in the United States and one of the few in the world that exemplifies the second mode of occurrence. For a number of years a small and sporadic production has come from this locality and has been used mainly in experimental work and for museum specimens. Pitchblende has been found in seven mines of Quartz Hill, all within an area of less than one-fourth of a square mile in extent. (See Pl. X.) All these mines have produced sulphide ores of gold and silver, and in most of them the pitchblende has been of very subordinate importance.

Microscopic study of the ores shows conclusively that the uraninite is intergrown contemporaneously with chalcopyrite and probably with quartz and pyrite, but that it is sharply cut by veinlets composed of galena, sphalerite, chalcopyrite, pyrite, and quartz. The minerals contemporaneous with the uraninite are those characteristic of the pyritic type of gold-silver ores, whereas the minerals of the transecting veinlets are those characteristic of the galena-sphalerite type of gold-silver ores. From the evidence available it therefore appears probable that the uraninite ores form merely a local and unusual variety of the pyritic type of gold-silver ores. They appear to represent a mineralogic variation of the same order as the occur-

[1] Rickard, T. A., The veins of Boulder and Kalgoorlie: Am. Inst. Min. Eng. Trans., vol. 33, p. 68, 1902.

[2] Lindgren, Waldemar, Some gold and tungsten deposits of Boulder County, Colo.: Econ. Geology, vol. 2, pp. 453–468, 1907.

rence of enargite in some of the pyritic veins near Russell Gulch. The Quartz Hill deposits contrast strongly with the pitchblende deposits of Cornwall and the Erzgebirge in their entire lack of nickel and cobalt minerals.

TUNGSTEN ORES.

The tungsten ores of Boulder County have been described at length by George and Crawford[1] and were not investigated in detail by the present writers. The principal mineral is ferberite, but with it are associated in small amounts several of the minerals scheelite, pyrite, chalcopyrite, galena, sphalerite, molybdenite, gold tellurides, and possibly fluorite and adularia. While no conclusive proofs have been obtained, these mineral associations have led most of the geologists who have studied the deposits to believe that they are closely related to the gold-silver deposits of the region and are probably of nearly the same age. Three features noted by the present writers appear to have a bearing on their origin and their relation to the other ore classes of the region: First, in the region where the tungsten ores are most abundant they almost wholly supplant other types of ores. Second, they occur in the only part of the quadrangle in which Tertiary dikes of andesitic or basaltic composition are abundant and adjacent to the only monzonite stock which exhibits extreme differentiation into dark-colored rocks, including iron ores. Third, the tungsten district lies between an area of productive gold-silver veins on the west and a region barren of valuable mineral deposits on the east. These relations and the mineral associations already cited are in harmony with the view provisionally adopted by the present writers that the tungsten ores represent an unusual phase of the general Tertiary mineralization of the region and that their origin is possibly connected in some way with the unusual development of dark-colored iron-rich rocks within the monzonite magmas of the area between Nederland and Caribou.

COPPER ORES.

In a region characterized by fissure veins that are valuable mainly for the gold and silver they contain the copper ores of the Evergreen mine, near Apex, stand unique as regards both mineral character and mode of occurrence. Their unusual features attracted the attention of Étienne Ritter,[2] who showed that the copper sulphides crystallized contemporaneously with the other minerals of the rock.

The primary ore minerals of the Evergreen mine are bornite and chalcopyrite. These minerals do not occur in fissure veins, but as con-

[1] George, R. D., and Crawford, R. D., The main tungsten area of Boulder County, Colo.: Colorado Geol. Survey First Rept., 1908.

[2] Ritter, É. A., The Evergreen copper deposit, Colorado: Am. Inst. Min. Eng. Trans., vol. 38, pp. 751–765, 1908.

stituents of dikes of monzonitic composition that are clearly offshoots from neighboring monzonite stocks. In places the monzonite has so shattered the schist and pegmatite wall rock that an igneous breccia has resulted. Chalcopyrite and bornite occur in the igneous matrix of this breccia, but not in the wall-rock fragments. In addition to its sulphide content, the monzonite of the Evergreen mine exhibits other unusual features; it carries small prisms of wollastonite locally in great abundance, and in a few places, in close association with the sulphides, it contains garnet.

The bornite does not appear to be an alteration product of the chalcopyrite, for the occurrence of bornite inclosed by chalcopyrite is as common as the reverse relation, and the bornite does not rim the chalcopyrite or follow incipient fractures in it. On the contrary, the two minerals are very irregularly associated, locally in a fashion resembling a graphic intergrowth. The chalcopyrite and bornite do not appear to be replacements of the silicates of the monzonite, although they may have corroded the silicates slightly in places; on the contrary, they appear to have crystallized at essentially the same time as the rock silicates.

Rogers,[1] in a recent paper, figures chalcocite associated with bornite from the Evergreen mine and suggests that the chalcocite is a product of upward enrichment. Chalcocite is a very inconspicuous mineral at this mine and is seldom recognizable except under the microscope. In one of the specimens examined chalcocite is irregularly associated with chalcopyrite and bornite. The origin of this particular chalcocite is uncertain. In most other specimens, however, chalcocite has developed along incipient fractures in the bornite and along contacts between bornite and silicate minerals. This relation between chalcocite and bornite is totally different from the relation between bornite and chalcopyrite and is taken to indicate that the chalcocite is secondary. As the mine workings are all shallow it is impossible to say whether the chalcocite was deposited by ascending or by descending solutions, but the writers are much inclined to accept the latter and more usual explanation of its origin.

The writers believe that the dominant sulphides of this mine, chalcopyrite and bornite, were probably concentrated by differentiation from the monzonite magma, and that the wollastonite and garnet of the ore-bearing dikes indicate an absorption of calcareous material from wall rocks.

The ore obtained at this mine is said to average about 3 per cent of copper and $4 to $5 to the ton in gold and silver. Its distribution, however, is irregular, and with the exception of the large chamber stope on the tunnel level no large bodies have been encountered.

[1] Rogers, A. F., Secondary sulphide enrichment of copper ores with special reference to microscopic study: Min. and Sci. Press, Oct. 31, 1914, p. 686.

Only a few carloads have been shipped, and the work is still largely exploratory. The ore is unquestionably to be sought in and near the dikes, but as the sulphides are so unevenly distributed in the dike rock no prediction of the probable value or extent of the ore can be made.

TITANIFEROUS IRON ORES.

The Tertiary monzonite stocks of Caribou and of Bald Mountain, northwest of Caribou, unlike the other monzonite stocks of the region, inclose a number of bodies of dark-colored rock that are clearly products of differentiation within the monzonite magmas. The extreme products of this process are several bodies of iron ore that show some interesting features bearing on the origin of titaniferous iron ores and the mechanism of magmatic differentiation.

The greater part of the Caribou and Bald Mountain stocks consists of monzonite and quartz monzonite of gray color and medium coarseness. Inclosed within these rocks and forming not more than 5 per cent of the surface of the stocks are a number of small irregular bodies of dark-colored rocks rich in iron-bearing minerals. The largest of these bodies is only about a quarter of a mile in greatest diameter. Within these areas of dark-colored rock in turn occur small bodies of titaniferous iron ore. In places the contacts between the iron ore and the dark rock that incloses it and between the dark rock and the monzonite are sharp, but in many other places complete gradations occur between these rock types, so that in general it is clear that the iron-rich rocks were differentiated from the monzonite magma, the differentiation being followed locally by intrusion of the darker into the lighter types. The rocks present are quartz monzonite, monzonite, olivine monzonite, gabbro, hornblende gabbro, hornblendite, magnetite-rich gabbro, magnetite peridotite, and magnetite pyroxenite.

The ores have been studied by Jennings,[1] who says: "These interesting deposits have little or no economic importance, but are excellent examples of iron ores of igneous origin." Singewald,[2] who has also studied the deposits, concludes that, "The best of the ore is only medium grade and the ore lenses are very small. On account of its small size the deposit can never have any economic value."

As is well known, no iron ores containing appreciable amounts of titanium are now used in the iron industry, though experiments looking toward their utilization are now in progress. The presence of titanium is not injurious in steels used for certain purposes; in

[1] Jennings, E. P., A titaniferous iron ore deposit in Boulder County, Colo.: Am. Inst. Min. Eng. Trans., vol. 44, pp. 14–25, 1913.

[2] Singewald, J. T., The titaniferous iron ores in the United States: U. S. Bur. Mines Bull. 64, pp. 126–128, 1913.

fact, titanium is the material most widely used to give steel certain desired properties. Its detrimental effect in an iron ore is due to the fact that it produces a refractory slag that is difficult to handle in the blast furnace, and 0.5 per cent seems to be almost as detrimental in this respect as 10 or 15 per cent. The percentages of magnetite and titanic oxide in samples of the Caribou ore analyzed by Jennings and by the Geological Survey are as follows:

	1	2	3
Magnetite (Fe_3O_4)	64.73	30.55	23.90
Titanic oxide (TiO_2)	4.48	2.69	2.53

1, E. P. Jennings, analyst; 2, 3, lean ore, George Steiger, analyst.

Even if the metallurgic difficulties involved in the high titanium content can be overcome, the inaccessibility of these deposits and their small size preclude all possibility of successful exploitation.

DOWNWARD ENRICHMENT.

GENERAL CONDITIONS.

It is well known that when the surface portions of ore deposits are attacked by the gases of the atmosphere and by water of surface origin and the dissolved substances it contains a part of the ore is carried away, either mechanically or in solution, while another part remains behind. The metals carried away may become widely scattered and lost, so far as concerns the miner of to-day, or they may be concentrated elsewhere in ore deposits of different types, such as the gold-bearing gravels of the district here described or the copper ores found in surface sandstones in other districts. The metals that remain behind work their way downward into the ore body, either mechanically or in solution; those carried mechanically do not penetrate far and those descending in solution are liable to reprecipitation through agencies that will be noted later.

Such processes as those outlined above must, at their beginning, as when erosion first exposes an ore body, result in a depletion in the value of the surface ore, but as erosion progresses the metals left behind come in time to represent a residuum from tens, then hundreds, and perhaps thousands of feet of ore that has been eroded away. To use a commercial simile, the value of the ore in the upper part of a deposit may thus increase "at compound interest." Such a process is termed "downward enrichment," the adjective being used to distinguish it from enrichment caused by ascending thermal solutions.

The gold-silver ores are the only ones in this region that have been affected in any considerable degree by downward enrichment, but

as these constitute the dominant ore class, the process has been one of much importance. Enrichment in one or all of the metals gold, silver, and copper has taken place; enrichment in lead and zinc has been insignificant. As in most mountainous regions, the ground-water level is very irregular; in most veins it originally stood 50 to 150 feet below the surface.

GOLD ENRICHMENT.

Weathering of the ore in the oxidized zone results in a partial freeing of the gold from its matrix, thus exposing it to mechanical concentration and to the solvent action of waters that enter the upper parts of the lodes. The enrichment in gold observed in the oxidized zone of ore bodies is probably in large part the result of mechanical concentration during weathering, a process well understood and requiring no discussion here, but solution and redeposition of gold may also have taken place. It would be expected that whatever gold was taken into solution would soon be reprecipitated, for it is well known that ferrous sulphate and most of the common sulphides, including pyrite, chalcopyrite, and galena,[1] are very effective precipitants of gold from a chloride solution. As several of these precipitating agents are abundant in the lower part of the oxidized zone it appears unlikely that much gold in solution[2] could successfully pass them; if it did it could hardly travel far below the water level before being precipitated by the primary sulphides. These deductions appear to be borne out by the facts of field observation, which afford abundant evidence of enrichment in gold in the oxidized zone but no certain evidence of gold enrichment below it.

Enrichment in gold in the oxidized zone is characteristic of all the types of gold-silver ores in the region—the pyritic ores, the galena-sphalerite ores, the composite ores, and the telluride ores. Its effects are most striking, however, in certain ores of the galena-sphalerite type which, where unoxidized, carry only negligible amounts of gold, usually less than 0.1 ounce to the ton, whereas where oxidized they may carry 1.5 to 3 ounces of gold to the ton. These are the so-called silver veins whose surface portions were worked by the pioneers for gold alone.

Although data showing in a systematic way the distribution of gold below the oxidized zone are rather meager, such information as is available fails to indicate much gold enrichment below the water level. In the Iron mine, in Russell Gulch, for example, which develops a typical pyritic vein, complete records of a careful sampling

[1] Palmer, Chase, and Bastin, E. S., Metallic minerals of precipitants of silver and gold: Econ. Geology, vol. 8, pp. 156–160, 1913.

[2] No account is here taken of colloidal gold solutions, of whose importance in nature little is known.

of all parts of the vein fail to show any systematic change in the gold content below the oxidized zone.

SILVER ENRICHMENT.

Silver enrichment contrasts strongly with gold enrichment in this district in that there is impoverishment rather than enrichment of silver in the oxidized zone and notable enrichment below the oxidized zone. Furthermore, silver enrichment is practically confined to the one type of galena-sphalerite ores. The primary silver minerals of the region are silver alloyed with gold and silver-gold tellurides. Argentite has not been authoritatively reported. The secondary silver minerals are native silver, cerargyrite, pearceite, polybasite, and proustite.

It is well known that silver is more readily taken into solution in the oxidized zone than gold and that fewer metallic minerals can reprecipitate it.[1] The poverty in silver of the oxidized zone is thus readily understood.

In most mine waters of surface origin the principal negative radicles present are Cl, CO_3, HCO, and SO_4. As compounds of silver with all these radicles are known, it is customary to consider the dissolved silver as existing in distributed balance with as many of these radicles as may be present. Most of the silver balanced by chlorine is likely to be reprecipitated in the oxidized zone as the difficultly soluble silver chloride (cerargyrite or horn silver). Cerargyrite is not a common silver mineral in this district, and its rarity is attributed to the low chlorine content of the surface waters. The silver balanced by carbonate and sulphate radicles may pass downward below the oxidized zone. In sulphide ore bodies like those under consideration most of the silver is presumably in balance with SO_4.

The silver is redeposited below the ground-water level principally as pearceite and proustite and very subordinately as polybasite and native silver in vugs or fractures in the primary ore or as replacements of the primary ore minerals, both metallic and nonmetallic. It is significant that in the ores of this region arsenic greatly predominates over antimony, both in the primary ore, where it occurs principally in tennantite, and in the enriched ores, where it occurs in pearceite and proustite. The chemistry of the formation of the arsenosulphides of silver is too little understood to justify discussion in a summary of this kind, but geologic observations in this region suggest some limiting conditions that may be a guide to experimental chemical work.

The first point is that the ores carrying secondary arsenosulphides of silver almost invariably carry abundant primary siderite or calcite; the solutions that deposited them were therefore not highly acid.

[1] Palmer, Chase, and Bastin, E. S., op. cit., pp. 169–170.

A second significant observation is that downward enrichment in silver is practically confined to ores of the galena-sphalerite type in spite of the fact that primary silver is abundant in all the other types of gold-silver ores. The dominant minerals of the veins showing silver enrichment are galena, sphalerite, and carbonates (calcite, siderite, or rhodochrosite, one or all); pyrite and chalcopyrite are present in smaller amounts. In the pyritic type of ores, in which silver enrichment is conspicuously absent, pyrite and quartz are the dominant minerals, and tennantite and chalcopyrite are less abundant.

The causes for this restriction of silver enrichment to veins of a certain mineral composition are undoubtedly complex, but the presence of carbonate gangue minerals in the ores that show silver enrichment is believed to be a most important factor. Their presence has led to an early neutralization of the free sulphuric acid in the descending silver-bearing solutions. Much of the carbonate in these veins is ferruginous (ferruginous calcite and siderite), and this by reaction with sulphuric acid yields ferrous sulphate, an effective silver precipitant. In a timely and suggestive paper Nishihara[1] has compared the neutralizing effect of various carbonates, silicates, and sulphides on sulphuric acid and their activity in reducing ferric sulphate to ferrous sulphate. It is very significant that pyrite, quartz, and chalcopyrite, the principal minerals of the pyritic type of ores, were in Nishihara's experiments comparatively ineffective in neutralizing sulphuric acid and in reducing ferric to ferrous sulphate. Galena and sphalerite and, of course, the carbonates are comparatively efficient in neutralizing sulphuric acid and galena is fairly active in reducing ferric sulphate. Furthermore, galena and sphalerite in solutions of sulphuric acid or ferric sulphate generate hydrogen sulphide, which may precipitate secondary sulphides. Nishihara has also shown that apparently pure galena from several localities, among them Idaho Springs, carries small percentages of manganese, which presumably occurs as the manganese sulphide alabandite mixed with the galena. This sulphide evolves hydrogen sulphide very actively when in contact with acid sulphate solutions, and if present in the enriched veins of this region may have exerted a considerable precipitative influence.

It appears, therefore, that the mineral composition of the galena-sphalerite veins that show enrichment is such as to favor early neutralization of acidity of the silver-bearing sulphate solutions descending from the oxidized zone, the formation of ferrous sulphate at the expense of ferric sulphate and sulphuric acid, and the development of hydrogen sulphide. All these features are believed to favor silver precipitation. In the ores of the pyritic type, on the other

[1] Nishihara, G. S., The rate of reduction of acidity of descending waters by certain ore and gangue minerals and its bearing upon secondary sulphide enrichment: Econ. Geology, vol. 9, pp. 743–757, 1914.

hand, the conditions favor the persistence of acidity and the retention of the iron in the ferric state; silver taken into solution in the oxidized zone is therefore likely to remain in solution and eventually to enter the general ground-water circulation and be lost so far as the local ore deposit is concerned.

In some of the deposits of the galena-sphalerite type, as for example those of the Topeka and Seaton veins, the primary ores are of workable grade, but in many others, as for example those near Lawson and on Silver Hill, north of Blackhawk, only the ores that have been enriched in silver can be profitably mined. These secondary ores form the typical silver ores of the miners of this region, their gold content being characteristically small. The workability of any of the primary ores is usually due to the fact that the primary gold content, rather than the primary silver content, is above the average.

Veins in which silver enrichment of the type here discussed has taken place to a considerable extent occur principally in four localities—(1) near Lawson and Empire station, (2) on or near Seaton Mountain, north of Idaho Springs, (3) on Silver Hill, near Blackhawk, and (4) near Caribou, with occasional occurrences elsewhere.

The silver content of the enriched ores shows much more variability than that of the primary ores. This is obviously due to the occurrence of the secondary silver minerals in fractures and as localized replacements rather than in even distribution through the ore. The silver content of ores of smelting grade varied from a few tens of ounces up to a thousand ounces to the ton, or even more in picked lots; 6½ tons shipped in 1870 from the Idaho mine, near Caribou, averaged 977½ ounces of silver to the ton, and two lots of ore from the Almaden mine, on Fall River, gave on assay, according to the manager of the property, the following extraordinary results in ounces to the ton:

	Gold.	Silver.
149 pounds	0.38	5,810.30
510 pounds	.487	4,084.92

The decrease in silver content of the enriched ores with increasing depth has been the prime factor in the decline of the silver mines of this district, but a factor of subsidiary importance was the great decrease in the market value of silver, from $1.32 an ounce in 1872 to 63 cents in 1894, a fall of about 50 per cent.

COPPER ENRICHMENT.

Downward enrichment in copper is not conspicuous in any of the mines and is of little economic importance. Commonly it is restricted to the development of thin films of chalcocite or bornite on chalcopyrite in the upper portions of pyritic ore bodies, but in

some veins of the galena-sphalerite type, as already mentioned, small amounts of secondary chalcopyrite are developed.

GENESIS OF THE PRIMARY ORES.

RELATION OF MINERALIZATION TO VOLCANISM.

The ore deposits of Gilpin County form part of a broad mineralized belt whose diverse types of ore deposits have one unifying feature, their invariable association with Tertiary igneous rocks. Beyond the regions characterized by these rocks the ore deposits disappear. This association, suggestive though it may be, would certainly not be sufficient basis for concluding that the ores and the Tertiary igneous rocks are genetically related, were it not for the fact that a similar association of ores and igneous rocks characterizes practically every region where lode deposits of gold and silver have been studied geologically. Furthermore, it seems probable from the geologic observations within this region that the mineral veins were formed late in the period of "porphyry" intrusion, for the veins are younger than most of the "porphyry" but older than a few scattered "porphyry" dikes. Finally, two classes of ores, the titaniferous iron ores and the Evergreen copper ores, are products of differentiation from the monzonite magmas. It is believed, therefore, that a genetic connection exists between the mineral veins of this region and the Tertiary igneous rocks.

AGENT OF ORE DEPOSITION.

With the exception of the iron and copper ores just mentioned, all the ore deposits of the region are believed to have been deposited by thermal solutions which escaped from the "porphyry" magmas, probably during their crystallization. The "porphyries" now exposed at the surface may have given off solutions that deposited ores at horizons above the present surface, but the solutions which deposited the veins and stockworks came from bodies of igneous rock that are still deeply buried, as is shown by the fact that the veins, with few exceptions, cut the "porphyries" now exposed. There appears to be no basis for the belief locally current that the occurrence of an ore deposit in or near "porphyry" is a favorable indication; the relations between ores and "porphyries" are of a much larger and more generalized order than that implied in any such concept.

REGIONAL VARIATIONS IN MINERALIZING SOLUTIONS.

Not only did the composition of the mineralizing solutions change during the ore-forming period, as is shown below, but there is evidence that solutions which were strictly contemporaneous were

of different composition in different parts of the district. The ores of the pyritic type, for example, appear to have been deposited about contemporaneously in the early part of the mineralization period, yet among these are several subtypes, narrowly restricted in distribution, which show mineralogic peculiarities. Such are the enargite and fluorite bearing veins and the pitchblende veins whose limits of distribution are shown in Plate X. Similar variations occur in ores of the galena-sphalerite type—for example, the occurrence of rhodochrosite in a few veins on Seaton Mountain and near the head of Gilson Gulch. Such variations can not be satisfactorily explained by differences in the nature of the wall rocks or in other external conditions and must be attributed to local peculiarities in the composition of the solutions that rose through the fissures and deposited the ores.

SEQUENTIAL VARIATIONS IN MINERALIZING SOLUTIONS.

It has been shown by a large number of observations in this region that where the sulphide ores of the two principal types, the pyritic type and the galena-sphalerite type, occur together, the pyritic ores are invariably the older. The periods during which the ores of the two types were deposited were separated by an interval long enough for the fracturing of the pyritic ores by renewed movement along some of the veins and for the development of some entirely new fractures. This interval may not everywhere have been of the same duration, but probably, in geologic terms, it was short and is to be interpreted as an episode in a single general ore-forming period rather than as a notable interval between two distinct periods. Certainly the ores of both types were deposited under similar general conditions as regards depth and temperature, followed the same or parallel lines of fracturing, and have, broadly, the same distribution. At Leadville, within the same great mineral province, where ores similar to the pyritic and galena-sphalerite types of this quadrangle are also present, the pyritic portions of the ores were, in general, the first to be deposited, but, according to J. D. Irving,[1] there is no evidence of an interval between their deposition and the deposition of the portions of the ores rich in galena and sphalerite. Evidence of an interval, if present, would presumably be less readily recognizable in replacement ores like those of Leadville than in ores that are fissure fillings, or it may be that the mineralization which progressed pulsatingly in Gilpin County progressed more uniformly at Leadville.

TEMPERATURE AND PRESSURE OF ORE FORMATION.

For his concept of the temperature and pressure under which ore deposits were formed the geologist is dependent upon (1) physio-

[1] Oral communication.

graphic and stratigraphic evidences of the extent of erosion subsequent to mineralization, (2) direct laboratory data in regard to the range of stability of ore minerals, and (3) indirect knowledge of the conditions under which certain ore minerals are stable, based on estimates of the amount of postmineral erosion in a large number of mining districts. Through the application of one or more of these criteria it is generally possible to determine whether the ores were formed under conditions of great, moderate, or slight intensity as regards temperature or pressure, or both, even though it may not be possible to express these conditions accurately in degrees of temperature or in pounds per square inch of pressure.

The application of the first of these criteria to the Gilpin County deposits is attended by many uncertainties, but from the data available 7,000 to 11,000 feet appears the most probable depth of formation of most of the deposits. At a depth of 9,840 feet (3,000 meters) the hydrostatic pressure would be about 300 atmospheres and the rock pressure about 810 atmospheres. Under the normal increase of temperature with increasing depth the temperature at a depth of 9,000 feet would be about 100° C. This may be regarded as the minimum possible temperature of ore formation, but it gives no clue to the actual temperature.

The mineralogy of the ores is presented in the accompanying table, which shows that in all the ores believed to be deposits from thermal waters there is an entire absence of minerals characteristic of very high temperature, high pressure, or both, or of low temperature and shallow depth. The absence of silicates, except adularia and sericite, is noteworthy. Oxides, except silica, are not present as primary minerals. Pyrrhotite, a sulphide characteristic of intense conditions, is absent. Chalcedony, a mineral occurring usually in deposits of shallow origin, though locally in those formed under conditions of moderate intensity, is present only in small amounts in a few telluride veins. Realgar, orpiment, stibnite, and many other minerals characteristic of deposits formed at slight depth are absent. On the other hand, tennantite and enargite, which are commonly found in deposits formed under moderately intense conditions, are abundant in certain of the veins of this region.

The mineralogic as well as the physiographic and stratigraphic evidence therefore points to the formation of the gold-silver lodes, the pitchblende ores, and probably also the tungsten ores under conditions of moderate intensity. The depth of formation was probably 7,000 to 11,000 feet. Direct evidence of the temperature of formation is lacking, but from analogy with similar deposits elsewhere its probable limits may be placed at 150° to 300° C.

The following table includes minerals developed metasomatically in wall rocks, as well as those that are fissure fillings:

Ore minerals of Central City quadrangle, Colo.

[P, Primary minerals; S, minerals of secondary sulphide zone; O, oxidation products; * mineral rare.]

Minerals.	Primary ores crystallized from magmas.						Primary gold-silver ores deposited by ascending thermal solutions under moderately intense conditions.								
	Caribou iron ores.			Evergreen mine copper ores.			Pyritic ore type.			Galena-sphalerite ore type.			Telluride ores.		
Native elements:															
Gold				P			P	S?	O	P	S?	O	P	S?	O
Silver				P			P	S?	O?	P	S	P	P	S?	O?
Copper									O						
Bismuth							P*			P*					
Sulphur									O			O			O?
Sulphides:															
Pyrite				P?			P			P			P		
Chalcopyrite				P			P	S*		P	S				
Bornite				P				S		P*	S*				
Covellite								S							
Chalcocite								S			S*				
Galena				P?			P*			P	S*				
Sphalerite				P?			P*			P					
Molybdenite							P*			P*			P*		
Bismuthinite							P*								
Tellurides:															
Sylvanite							P?			P?			P		
Petzite													P*		
Sulpho-compounds:															
Tetrahedrite							P*			P?					
Tennantite							P			P					
Enargite							P			P*					
Pearceite											S				
Proustite											S				
Polybasite											S				
Stephanite											S?				
Haloids:															
Cerargyrite												O*			
Fluorite							P			P?					
Oxides:															
Quartz				P			P			P			P		
Chalcedony													P		
Tenorite									O*						
Hematite			O			O			O			O			O
Zincite												O*			
Ilmenite	P														
Ilsemannite ($MoO_2.4MoO_3$)															O*
Magnetite	P			P											
Limonite			O			O			O			O			O
Carbonates:															
Calcite				P?	S*		P			P					
Siderite							P			P					
Rhodochrosite										P					
Smithsonite												O*			
Cerusite												O*			
Malachite						O			O			O*			
Azurite						O			O			O*			
Aurichalcite												O*			
Silicates:															
Orthoclase				P											
Adularia										P*			P*		
Soda-potash feldspar							P*								
Albite				P											
Plagioclase (calcic)	P			P											
Augite	P			P											
Wollastonite				P											
Garnet				P											
Olivine	P														
Zircon				P											
Sericite							P			P			P?		
Biotite	P														
Epidote										P*					
Roscoelite													P		
Chlinochlore										P*					
Serpentine			O												
Calamine												O*			
Titanite				P											
Phosphates:															
Apatite	P														
Uranates:															
Uraninite							P*								
Sulphates:															
Barite										P			P*		
Hydrous sulphate of iron and copper						O			O						
Basic sulphate of uranium, exact composition not determined, found coating uraninite at Wood mine, canary-yellow									O						
Goslarite													O*		

COMPOSITION OF MINERALIZING SOLUTIONS.

The composition of the solutions which deposited the gold-silver ores and pitchblende ores may be inferred in a qualitative way from the mineralogy of the ores and the wall-rock alterations. To summarize without detailing the evidence, it appears that these solutions were alkaline or neutral in character and that they were rich in alkali earths; during the early stages of the mineralization they were rich in iron and silica and during the later stages rich in lead, zinc, carbonate, and bicarbonate; they carried smaller amounts of copper, arsenic, antimony, gold, and silver, and locally they carried manganese, sulphate, barium, tellurium, fluorine, uranium, and vanadium.

THE AZTEC GOLD MINE, BALDY, NEW MEXICO.

By Willis T. Lee.

INTRODUCTION.

Interest has recently been revived in the Aztec mine at Baldy, Colfax County, N. Mex., which was first described by Raymond [1] in 1870 and later by Jones [2] and Graton,[3] by the discovery of a large body of high-grade gold ore. This mine, situated on the Maxwell land grant, was a famous producer 45 years ago, but after the exhaustion of the body of ore then worked the mine attracted little attention. An adit, started a few years ago, was driven through several small deposits of moderately rich ore and in August, 1914, entered a large body of high-grade ore. This ore body has yielded good returns. Its extent had not been ascertained at the time of the writer's investigation in July, 1915.

DISCOVERY AND DEVELOPMENT.

The Aztec mine, owned and operated by the Maxwell Land Grant Co., is situated at an altitude of more than 10,000 feet above sea level, on the eastern slope of Baldy Peak, which reaches an altitude of nearly 12,500 feet. The mine is connected by wagon road with Ute Park, the present terminus of the St. Louis, Rocky Mountain & Pacific Railway, a branch line of the Santa Fe System. According to a published report the gold was discovered on Baldy Peak by a man prospecting for copper, which had previously been found there. The account states that an Indian who came to Fort Union on a trading expedition exhibited some specimens which he had picked up on the peak. The white men at the fort recognized them as copper ore and sent one of their number with the Indian, who showed him where the ore was found. This resulted in the location of a prospect which for several years was known locally as the Copper mine, but which later became known as the Mystic lode. It is on the west side of Baldy Peak, near the top, at an altitude of about 12,200 feet.

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1869, pp. 385-388, 1870.

[2] Jones, F. A., Mines and minerals of New Mexico, pp. 144-151, 1904.

[3] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 92-105, 1910.

A considerable amount of development work was done at various times on this prospect, but its great altitude and its distance from a railroad shipping point prevented profitable operation. However, when a railroad was constructed to Ute Park in 1906 it was thought that some of the best ore might be shipped with profit. One carload, yielding 20 per cent of copper, was later sent to the smelter. At the time of the writer's visit another carload was ready for shipment. The ore is carried by burros down the mountain to Baldy and thence carted by wagon to Ute Park, a distance of 8 miles. The present opening is not sufficiently developed to permit a determination of the size of the ore body or its relation to the rocks containing it, but from what may be seen it is probable that the ore occurs in a fissure vein. It consists of chrysocolla and cuprite, the former predominating. The cuprite occurs as dark-red, clearly defined angular fragments embedded in the bluish-green chrysocolla, the mass resembling a cemented breccia.

According to the published account a party sent out in 1866 to do development work on the copper prospect found placer gold on Willow Creek, on the west slope of Baldy Peak, in October of that year. The news of this discovery spread rapidly, and in the summer of 1867 placer mining was begun in this region, which later became known as the Elizabethtown district. These placers were worked for several years, and according to Jones [1] about $2,250,000 worth of gold was recovered. However, the scarcity of water made operation expensive, and although only a small part of the placer ground has been worked, no extensive operations have been carried on there for several years. The placer gold was found only along streams heading on Baldy Peak, and this led to a search of its slopes for the lode. In June, 1868, the outcrop was discovered, and later the Aztec mine was opened on it. The mine was rapidly developed, and a 15-stamp mill was put into operation October 29, 1868. For a few years the yield was sometimes as high as $21,000 a week. Raymond [2] reported in 1870 that ore from this mine averaged as high as $68.83 a ton saved on the plates. It is estimated, according to Graton,[3] that the total amount of gold taken from this mine was "between $1,250,000 and $1,500,000, of which about $1,000,000 was taken out in the first four years."

This mine brought the district into prominence and is said to have been the immediate cause of the sale to an English syndicate of the Maxwell land grant, consisting of 1,750,000 acres. The original grant was made by Mexico in 1843, but its boundaries, as claimed, were called into question by the officials of the United States Government until 1861, when Congress confirmed the grant. The body

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[1] Jones F. A., op. cit., p. 145. [2] Raymond, R. W., op. cit., p. 387. [3] Graton, L. C., op. cit., p. 97.

of the ore which had yielded the rich returns was soon exhausted. In 1872 the mine became involved in litigation and mining operations ceased. Thereafter for more than 40 years occasional efforts were made to find other bodies of paying ore. Accounts of these attempts are contained in the reports cited. The sedimentary rocks of the district are faulted and intruded by igneous rock in the form of dikes and sills. Near these bodies of igneous rock and in the zone of fracture many prospects have been opened, and in some of them small quantities of ore have been found, but none that yielded notable returns.

In 1909 J. T. Sparks, then in charge of the development work at Baldy, ascertained that a quartzose conglomerate, now known to constitute the base of the Raton formation in this region, is the "quartzite" and that the underlying Pierre shale, of Cretaceous age, is the "slate" of the old Aztec workings. He confined his attention to this contact and found ore in several places. In the extension of one of the entries started on this contact his successor, E. V. Deshayes, found the body of rich ore which is being worked at the present time.

GEOGRAPHY.

Baldy Peak (fig. 19) is the highest point of a prominent ridge which Graton called the Cimarron Range and which is separated from the main range of the Rocky Mountains by Moreno Valley, a troughlike basin draining eastward by a narrow canyon cut through this range by Cimarron River. Because of its great altitude Baldy Peak receives relatively heavy precipitation, but the mine is situated on the steep slope so near the head of Ute Creek that the streams are small and difficulty is experienced in obtaining enough water for mining operations. Farther down Ute Creek there is a small, steady flow that has been utilized for many years in placer mining.

GEOLOGY.

Only two sedimentary formations crop out in the vicinity of Baldy—the Pierre shale, of Cretaceous age, and the Raton formation, of early Tertiary age. At Ute Park and localities farther east the Pierre shale is overlain by the Trinidad sandstone and the Vermejo formation, both of Cretaceous age. The Vermejo contains the most valuable coal beds of the Raton coal field. These formations are overlain unconformably by the Raton formation, and between Ute Park and Baldy the Trinidad and Vermejo were eroded away before the sediments of the Raton were deposited, so that the Raton now lies across beveled edges of the older rocks, as indicated in figure 20.

The sedimentary formations, which were originally almost horizontal, are now faulted and upturned on the flanks of the mountain. Minor folds and small faults, formed probably at the time the beds

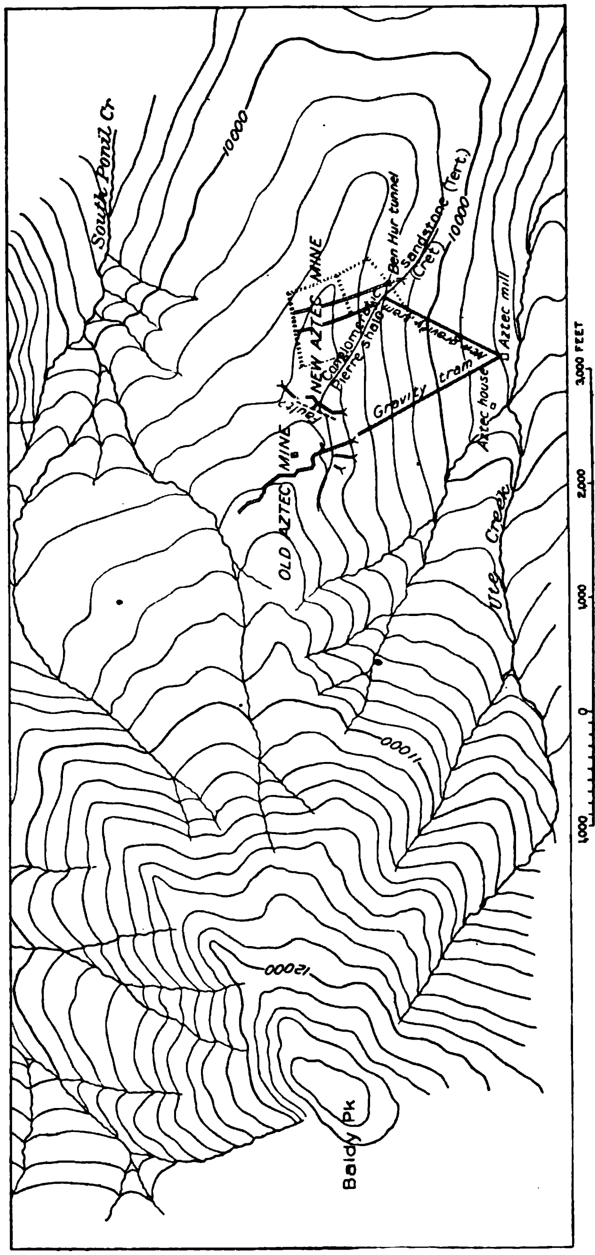

FIGURE 19.—Map showing Baldy Peak and Aztec mine, Baldy, N. Mex. From data furnished by the Maxwell Land Grant Co.

were upturned, antedate the deposition of the ore. The movements that produced these faults and folds occurred some time after the beginning of the Tertiary period, for the beds of early Tertiary age—the Raton formation—are involved in them.

The igneous rock of the district consists of quartz monzonite porphyry and occurs as dikes and sills. The sills are numerous, and many of them were intruded into the Pierre shale, although some occur also in the Raton formation; the dikes cut both formations. Inasmuch as these igneous rocks cut the Raton formation, the intrusion was of post-Raton date and possibly accompanied the uplifting of the sedimentary beds. A prospect tunnel driven into the west side of the mountain in penetrating a thickness of 1,400 feet of rock went through six sills aggregating 425 feet in thickness. As Graton has pointed out, these intrusive rocks have effected pronounced local metamorphism of the shales.

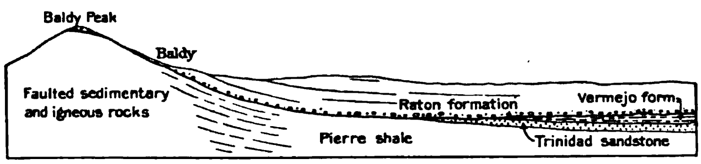

FIGURE 20.—Sketch profile through Baldy Peak and Aztec mine, Baldy, N. Mex., showing the unconformity between the Raton formation and the Pierre shale. The gold ore at Baldy occurs along this unconformity.

OCCURRENCE OF ORE.

The gold ore is clearly associated with the igneous rock, and many of the small ore deposits of the district are reported to occur at the contact of this rock with the shale. However, the principal bodies of ore known at the present time are not in immediate contact with the intrusive rock.

The principal bodies of ore near Baldy occur at the plane of the post-Cretaceous unconformity, where the basal conglomerate of the Raton formation rests on the Pierre shale. The ore was deposited during the Tertiary period, at some time later than the Raton epoch. Some of the ore is found in small pockets and stringers in the conglomeratic sandstone, but most of it that is worked at the present time is in the underlying shale, into which it extends for distances of a few inches to 5 feet or more. The richest and largest bodies occur on the down-slope side of the crests of the minor folds, as illustrated in figure 21.

The folding seems to have fractured the shale at the crests and opened minute fissures. Many of these openings are now filled with calcite, which appears as an intricate network in the shale. The calcite carries pyrite, chalcopyrite, sphalerite, and possibly galena. Pyrite also occurs very generally along the contact. The gold occurs

in part as wire gold or as thin irregularly shaped masses, as if deposited in cavities, but usually in minute particles coated with dark material, so that to the eye they do not appear metallic. In some places these particles appear to be rather generally distributed through the shale, but in others they occur especially in dark nodular masses of heavy fine-grained crystalline rock that apparently consist chiefly of chlorite. These masses are particularly sought for in mining, for they constitute the richest ore. Their origin was not ascertained.

The ore is free milling and is treated in a 10-stamp mill, by far the greater part of the gold being caught on the amalgamating plates. The concentrates are sent to the smelter and the tailings are impounded for future treatment.

Until recently the greater part of the ore mined came from the lower part of the conglomeratic sandstone or from the fractured portions of the shale close to the contact. Sparks found it mostly in a rusty zone between the sandstone and the shale in calcareous gangue matter, mainly as free gold but also in the sulphides. He reported "sulphides and arsenides of silver, copper, nickel, and cobalt" in association with the gold and stated that the sulphides occurred most abundantly near the contact, while the free gold was more often found along slips and fractures ranging from a few inches to a few feet in width both above and below the main contact. The gold-bearing solutions seem to have penetrated everything near the contact, but the rich ore body now being worked indicates that they deposited gold most readily in the shale. As elsewhere in this region, the conglomeratic sandstone contains small irregular masses of coal, probably derived from buried wood. A piece of such coal from one of the openings of the Aztec mine was assayed by E. E. Burlingame & Co., of Denver, who report that the ash from the coal runs 8 cents a ton in gold.

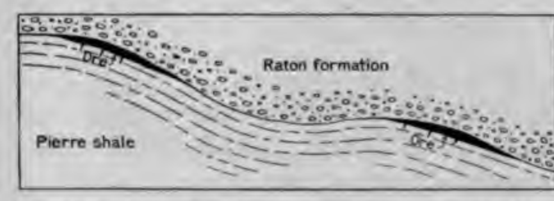

FIGURE 21.—Sketch profile illustrating the occurrence of gold ore on the down-slope side of anticlinal ridges at Baldy, N. Mex.

The ore handled at the time of the writer's visit was reported to range in value from $15 to $250 a ton. During the 10 months prior to the visit more than 2,100 tons had been treated, with an average return of $107.60 a ton. Of this yield 80 per cent was recovered by amalgamation and 20 per cent was derived from the concentrates. A small amount of gold, which will probably be recovered in time, still remains in the tailings.

A RECONNAISSANCE FOR PHOSPHATE IN THE SALT RIVER RANGE, WYOMING.

By G. R. MANSFIELD.

INTRODUCTION.

Scope of investigation.—In the autumn of 1914 a part of the Salt River Range was examined because of questions relating to certain withdrawn lands on the west flank of that range. The writer was asked to ascertain the presence or absence of important beds of phosphate west of the crest of the range and to procure such other data regarding the stratigraphy and structure of the range as proved practicable.

The examination was begun east of Fairview, Wyo., on September 24, 1914, with P. V. Roundy, of the Geological Survey, as chief assistant. E. L. Jones, jr., and E. H. Finch, of the Geological Survey, later joined the party, and work was continued northward along the range until October 9, when it was stopped because of deep snow on the mountains.

Previous work.—The region described in this report is part of the great area studied by the Hayden Survey, the reports and maps of which still constitute the main source of information on this district. Blackwelder[1] has given an account of the discovery of phosphate in Swift Creek, east of Afton, and Schultz[2] has discussed the geology of the region east of the crest of the Salt River Range.

Results.—The data thus far available indicate that the prosphate deposits of the Salt River Range are probably inferior to those of southeastern Idaho both in thickness and in quality. There is, however, a considerable body of medium-grade rock which may be considered as a valuable reserve deposit. If the plan of grinding and applying phosphate rock directly to the soil without chemical treatment is found to produce beneficial results, some local demand for this rock might be developed, for the westernmost portions of the deposit are readily accessible in the canyons of Dry, Swift, and Willow creeks, and the rock is largely above water level. Under present market conditions, however, and in view of the great body

[1] Blackwelder, Eliot, A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 460–461, 1911.

[2] Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, 1914.

of high-grade rock in neighboring regions of Idaho, there is little likelihood that the deposits of the Salt River Range will assume any notable importance in the near future.

GEOGRAPHY.

Topography.—The Salt River Range lies near the west boundary of Wyoming, in Lincoln County, east of the broad alluvial valley of Salt River, which is locally known as Star Valley. The range is separated on the north by the Snake River canyon from the Snake River Range. To the south it splits into two ranges that form divides between tributaries of Bear and Green rivers. The range is rugged and high, maintaining an altitude of 9,000 to 10,000 feet, and culminating in Mount Wagner, 10,809 feet high, toward its south end. The trend of the range is north or slightly to the west of north, and many of the ridges and valleys follow the strike of the rocks. The canyons are deep, rough, and picturesque. Some of the harder rock layers descend to the canyon bottoms as veritable walls of rock that project conspicuously above the adjacent weaker beds. Toward the heads of a number of the canyons there are relatively broad, open basins which lie for the most part along the strike of Triassic rocks that offer moderate resistance to erosional activity. Below these basins the canyons cross the disturbed massive limestones of the Carboniferous. Here the canyons tend to close, with steep rocky walls and rock slides that are difficult of passage. There are evidences of two or more physiographic cycles, but the history has not been worked out. Alluvial fans lie at the mouths of many of the canyons along the west base of the range. The town of Afton is located upon a large fan somewhat above the general level of Star Valley.

Drainage.—For most of its length the Salt River Range forms the divide between two large southerly branches of the Snake, Salt River and Grays River, but Grays River cuts across the range in its lower course shortly before entering Snake River. In the portion of the range covered by this report the main streams are all tributary to Salt River except Bear Creek, which heads against McDougal Pass and flows into Grays River, and Corral Creek, which heads against Swift Creek and flows eastward. The main streams that are discussed in this report are Dry Creek, in T. 31 N., R. 118 W.; Swift Creek, in T. 32 N., R. 118 W.; Phillips, Willow, and Dry creeks, in T. 33 N., R. 118 W.; and Strawberry Creek, in T. 34 N., R. 118 W. With the exception of Phillips Creek and the northern Dry Creek, these are all characteristic mountain torrents of good volume and are valuable as sources of water power as well as for irrigation. Large springs occur in a number of the canyons, and one of these in Swift Creek in the NW. ¼ sec. 23 (unsurveyed), T. 32 N., R. 118 W., is intermittent, having a periodic flow said to occur several times daily. This spring

was visited twice on different days. It was inactive on the first visit and just beginning activity on the second. In Strawberry Creek the surface flow is more or less intermittent in the upper and middle courses, but two considerable springs a short distance above the lower and more rocky part of the canyon supply practically the full volume of the creek.

Culture and industries.—The lowland outside of the range is largely taken up as agricultural land and is more or less actively farmed. Star Valley is an important district for the raising of grain and hay and for dairying. Dairies are located at Afton and Thayne. Most of the area directly concerned in this report lies in the Wyoming National Forest, the headquarters of which are at Afton. This part of the range is still largely unsurveyed and uninhabited, but it is extensively used for grazing. Timber and fuel are also cut in the national forest. A sawmill in the forest is maintained on the southern Dry Creek, in unsurveyed sec. 2, T. 31 N., R. 118 W. A sawmill has been operated for many years at the mouth of Willow Canyon, in sec. 14, T. 33 N., R. 118 W., and another sawmill is located at the mouth of Swift Creek canyon, at Afton.

Water power.—A small power plant at the mouth of the canyon of Swift Creek generates electricity for lighting and other uses at Afton. Its capacity is not sufficient, however, to supply much of the surrounding territory. Except at this plant and the sawmills above referred to no use is made of the water power in the creeks mentioned. Strawberry Creek, though admirably adapted for water power, having good volume and velocity, is entirely unutilized in its canyon portion, and Willow Creek, Swift Creek, and the southern Dry Creek are only partly utilized. The sawmill on Dry Creek is about 5 miles above its mouth, and the lower part of the canyon contains favorable power sites.

GEOLOGY.

GENERAL FEATURES.

Parts of the canyons of both Dry creeks and Swift, Phillips, and Willow creeks were traversed, a reconnaissance trip was made along Willow Creek to McDougal Pass and down Strawberry Creek to Bedford, and a similar trip was made down Willow Creek through the narrows below Turnerville to the narrows of Salt River and the region west of that stream.

The part of the Salt River Range examined includes sedimentary rocks ranging in age from early Carboniferous (Madison limestone) to Quaternary. No igneous rocks were seen. On the general map (Pl. XII) an attempt has been made to correlate the several canyon sections by drawing connecting lines from one canyon to the next. These lines, however, are purely hypothetical, for the formations

have not been traced through the areas intervening between the canyons. The accompanying table gives a summary of the rock formations present in the range:

Rock formations of Salt River Range, Wyo.

Age.		Formation.	Character.	Thickness (feet).
Quaternary.		Alluvium.	Unconsolidated sands and gravels.	
Tertiary.		Conglomerates.	Pinkish, calcareous, with subangular fragments of limestones and sandstones as much as 5 inches in diameter.	
Jurassic.		Twin Creek limestone.	Whitish shaly limestone; some massive beds; fossiliferous.	2,000±
Jurassic or Triassic.		Nugget sandstone.	Red sandstones, with some shaly beds and thin beds of purplish limestone.	1,100+
Triassic (Lower Triassic).		Ankareh formation.	Chocolate-colored to dark-red sandstones and shales.	1,000
		Thaynes limestone.	Limestones, sandstones, and calcareous sandy shales, greenish yellow; fossiliferous. Include also 200 to 300 feet of red beds.	2,100+
		Woodside shale.		
Carboniferous.	Permian (?).	Phosphoria formation.	Rex chert member, nodular cherty limestone 250 to 300 feet thick, underlain by phosphate shales 65 to 150 feet thick, containing several beds of phosphate rock; fossiliferous.	450
	Pennsylvanian.	Wells formation.	Siliceous limestone and sandstones; fossiliferous.	2,000+
	Mississippian.	Brazer limestone.	Massive gray limestones, generally light colored; fossiliferous, containing large cup corals.	1,500±
		Madison limestone.	Massive dark-bluish or brownish-gray limestones; fossiliferous.	2,500±

STRATIGRAPHY.

CARBONIFEROUS.

Madison limestone.—The Madison limestone was recognized in Strawberry, Dry, and Willow Creek canyons, in Tps. 34 and 33 N., R. 118 W., and may be present on Swift Creek. The formation consists of massive dark-bluish or brownish-gray, relatively pure limestones, with little or no sandy material. Some of the individual beds are thin, but the formation as a whole is resistant to erosion and forms rugged ledges and slopes where it is exposed in the canyons. Fossils are rather numerous and include small cup corals, gastropods, spiriferoid brachiopods, crinoids, and other types. The rock presents no new or unusual facies and is apparently like the rocks of the same age in other parts of the Idaho field, as described in previous reports. The distinction between the Madison and the Brazer limestone is not everywhere easy, for the two formations are massive and resemble each other lithologically to a certain extent. The relations of the Madison to the formations above and below are not clear, as it seems in this area to be separated from the adjoining formations by faults. Measurements on Willow Creek show 2,400 to 2,500 feet of rock

assigned to the Madison, and in Dry Canyon north of Willow Creek the thickness appears to be even greater. A number of folds and faults in these older rocks have been recognized, and allowance has been made for them in measuring the thickness. There may be within the formation, however, unrecognized faults which may have duplicated some of the strata, thus increasing the apparent thickness.

Brazer limestone.—The Brazer limestone is also a massive gray rock but is generally of somewhat lighter color than the Madison. It contains some sandy beds and is more or less cherty in places. Like the Madison, it forms rocky and rough slopes and prominent ledges. Fossils are fairly numerous and conspicuous. Among them are cup corals 4 to 8 inches or more long and 2 or more inches in diameter, with many fine septa, *Productus giganteus* and other brachiopods, Bryozoa, and Syringopora. The Brazer limestone here is similar to the rocks of the same age in Idaho and presents no unusual facies. On account of the faults and folds there has been no good opportunity to measure a complete section. The best exposures seen were in Swift Creek Canyon, where at least 1,500 feet of limestone may be assigned to this formation and the base was not recognized.

Wells formation.—The Wells formation has massive cherty limestones at the base but is more siliceous throughout than either the Brazer or the Madison. A varying portion in the middle or upper part is a sandstone, or in places even a quartzite. The upper 50 to 200 feet is made up of siliceous dense limestone that in places forms prominent ledges. This portion of the formation has sometimes been called the "underlying limestone," or the "lower Productus limestone," as it normally underlies the phosphate shales of the Phosphoria formation just above. The Wells formation as a whole is somewhat less resistant to erosion than the Madison and Brazer and forms rounded slopes. The canyons, too, are wider and less rugged in this formation than in the Brazer and Madison limestones. The limestones of the Wells are somewhat fossiliferous. The lower beds carry *Spirifer rockymontanus*, Schizophoria, Bryozoa, and other forms. The upper limestone is sparingly fossiliferous, the most noticeable forms being species of Productus. Excellent exposures of the Wells are found in all the canyons examined, notably those of Strawberry and Swift creeks. Measurements on Swift Creek show 2,000 feet or more of strata assignable to this formation.

Phosphoria formation.—As in the Idaho field the Phosphoria formation consists here of two members—the phosphate shales below and the Rex chert member above. The thickness of the shales is about 65 to 150 feet and of the chert 250 to 300 feet. A partial section of the shales was obtained from a prospect made by the Survey party in Willow Creek canyon about half a mile above the sawmill. The details of this prospect and the analyses of the samples taken are

given in the discussion of phosphate deposits (p. 339). A number of occurrences of the phosphate shales were noted, including several natural exposures. One of these is described more fully on page 340. The general characteristics of the shales appear to be much the same as in the Idaho field. The Rex chert member is more of a limestone in this region than in many parts of Idaho. It is a very prominent ledge maker where it is well exposed and forms steep walls in a number of places, none more striking than in Swift Creek, where it resembles a stockade nearly 50 feet high, descending the mountain side and crossing the canyon.

TRIASSIC.

Woodside shale and Thaynes limestone.—The Woodside and Thaynes formations were not satisfactorily differentiated in this region. Although a search was made for the Meekoceras zone, the boundary between the two formations, its presence was recognized at only one locality—in the float near the end of the traverse on the northern Dry Creek, about a quarter of a mile east of the northeast corner of unsurveyed sec. 6, T. 33 N., R. 117 W. A very fine section of these two formations is exposed near the crest of the range along the Willow Creek trail, half a mile or less south of McDougals Pass. There was no opportunity to measure this section, but the rock forms prominent cliffs and coarse débris at the locality named. Here silicified fossils, pelecypods, project from the weathered surfaces of rock fragments, as in the upper part of the Thaynes limestone of southeastern Idaho. The massiveness of some of the beds is remarkable. Large fragments, some 8 by 5 by 4 feet, were seen in the rock waste at the bases of the cliffs. Some of the beds are very sandy and form reddish to pinkish sandstones, which in places weather with black, iron-stained surfaces. These rocks resemble some of the sandstones in Dry Valley, Idaho, in T. 8 S., R. 44 E., which proved to belong to the Woodside and Thaynes formations but were at first mistaken for the Wells. In the exposures near McDougals Pass there are 200 to 300 feet of red beds. On Swift Creek measurements of the combined formations, which may not be complete, show 2,100 feet of strata.

Ankareh formation.—The Ankareh formation is represented in this region by a series of chocolate-colored to dark-red sandstones and shales. They are exposed in the canyons of the southern Dry Creek and Swift Creek and also on the headwaters of Willow Creek near McDougals Pass, where they overlie with apparent conformity the Thaynes limestone. The last-named locality furnishes an unusually fine exposure, but it was not practicable to study it at close range. On Dry Creek and Swift Creek the formation as measured is 750 and 1,000 feet thick, respectively. The lower figure on Dry Creek is probably due to partial removal by faulting.

JURASSIC OR TRIASSIC.

Nugget sandstone.—The Nugget sandstone occurs on the lower parts of the southern Dry Creek and Swift, Phillips, and Willow creeks, and also in the low hills west of Turnerville, at the narrows of Willow Creek. In the section south of McDougals Pass above mentioned the Nugget follows the Ankareh, but it was not ascertained if the complete thickness of the formation is present. The Nugget also appears in the upper part of the Swift Creek canyon. The Nugget sections in the lower canyons, where the more detailed observations were made, are all faulted to some extent, but from 800 to 1,100 feet of beds are represented. The rocks are the usual red sandstones with some shaly beds and thin layers of purplish limestone.

JURASSIC.

Twin Creek limestone.—The Twin Creek limestone is exposed in the canyons of the southern Dry Creek, Swift Creek, and Phillips Creek. It also appears to the west of the Nugget sandstone in the narrows of Willow Creek west of Turnerville. So far as observed the Twin Creek limestone is not fully represented in the sections examined but is partly cut out by faults. It is represented chiefly by the chippy and shaly rock that elsewhere seems to occupy the central part of the formation. Sections examined in the southern Dry Creek and Swift Creek indicate thicknesses probably greater than 1,700 and 2,000 feet, respectively. Fossils are not numerous in the more shaly beds of this formation, but Pentacrinus, Ostrea, and other forms occur in the thicker beds.

TERTIARY.

A conglomerate consisting mainly of subangular fragments of Carboniferous limestones and sandstones with some Triassic material of varying shapes and sizes, from a fraction of an inch to 4 or 5 inches in diameter, lies on the lower foothills along Phillips Creek east of Grover, above the narrows of Willow Creek west of Turnerville, and at the mouth of Strawberry Creek. The matrix is calcareous and the general color of the rock is pinkish. The attitude of the rock where observed is nearly horizontal or only slightly inclined. No fossils have yet been found in this rock, and its stratigraphic position is somewhat uncertain. In the field it was tentatively classed with the Salt Lake beds, of probable Pliocene age, as mapped by A. C. Peale, of the Hayden Survey. Some doubt is thrown on this interpretation by observations on similar rock north of Georgetown, Idaho, 30 miles or more to the southwest. It is possible that this conglomerate may prove to be of Wasatch age.

QUATERNARY.

Alluvial and fan deposits of Quaternary age occupy the lowlands along the west base of the range and in the basin west of the mouths of Willow, the northern Dry, and Strawberry canyons. These deposits are coarse bowldery gravels at the mouths of the canyons but consist of finer material farther away from the base of the mountains. The gravels at the mouths of the southern Dry Creek and Swift, Phillips, and Willow creeks and the smaller intervening creeks are abruptly truncated and form terraces 15 or 20 feet high.

STRUCTURE.

The general structure of the region described in this report is complex, and the available data are insufficient to warrant the attempt to carry the structure observed in any one of the several canyons across to the neighboring canyon. It is clear, however, that at least two great folds are involved, one anticlinorial and the other synclinorial, and that each is broken by a number of faults. The trend of both folds and faults is a little west of north. The planes of many of the faults appear to be steeply inclined, and the relations of the formations involved suggest normal faulting, because the structure as a whole does not indicate marked overturning. The folds appear to pitch gently southward, so that older beds are exposed in the northern canyon sections than in the southern sections. The oblique truncation of successive structures along the west base of the range in T. 31 N., R. 118 W., and farther north, together with the relative straightness and steepness of the mountain slope, suggests that the west base of the range is determined by a normal fault that is inclined toward the west and brings in Jurassic or higher formations, now concealed beneath the alluvium of Star Valley. These formations constitute the west wall of Star Valley, some 3 miles or more to the west. Relatively recent movement along such a line is suggested by fairly straight scarps or terraces 15 to 20 feet high in some of the larger alluvial fans along the west base of the range. These scarps, however, may be due to other causes. The map (Pl. XII) shows the broader structural features, and the geologic structure sections along several of the canyons show details and are discussed more fully below in the accounts of the canyons.

PHOSPHATE DEPOSITS.

The Phosphoria formation is involved in the folding and faulting so that it crosses each of the canyons examined except that of Phillips Creek. The canyons of the southern Dry Creek, Swift Creek, and Willow Creek are each crossed by the shales no less than three times between the crest of the range and its western base. The crest of the range was visited only at McDougals Pass, at the heads of Willow

and Strawberry creeks. It was nearly reached, however, on Swift Creek. Crossing the divide at Corral Creek and entering the headwater region of Swift Creek a band of phosphate shales runs along the west side of the crest of the range. This was not followed northward, but it falls in line well with another similar band that in like manner crosses the divide from the southeast at McDougals Pass above Willow Creek and descends northward in the headwater region of Strawberry Creek for a distance of perhaps 2 miles and then reascends toward the crest. It is not yet certain that the Swift Creek band and that of McDougals Pass are identical and continuous, but it seems likely that this will prove to be the case when the intervening territory is traversed. West of this band the phosphate shales are brought in twice by folding in the middle or lower parts of the canyons. The phosphate deposits continue southward from the southern Dry Canyon, but it is doubtful if they extend northward from Strawberry Creek. The extent of the formation in each direction was not determined.

The phosphate shales in this region have a thickness comparable to that of the beds of the same formation in the Idaho field. Phosphate beds of good quality are included in the shales. A section across the shales was measured in a series of prospect pits made by the Survey party near the mouth of Willow Creek, and samples were collected for analysis. The details of the section and the analyses are given in the following table:

Details of Survey prospect in the SW. ¼ NE. ¼ sec. 14, T. 33 N., R. 118 W., on Willow Creek.

[Field No. M 45-14.]

	P_2O_5.	Equivalent to $Ca_3(PO_4)_2$.	Thickness.	
	Per cent.	*Per cent.*	*Ft.*	*in.*
Phosphoria formation:				
k Phosphate rock, oolitic, dark brown to black, medium grained, folded in small syncline and anticline (end of third trench)—				
Sample 3, upper	11.90	26.00	1	7
Sample 2, lower	20.21	44.16	2	0
j Shale, calcareous, clayey, yellowish, with green tinge; breaks into small pieces with planes irregularly arranged			2	0
i Phosphate rock, oolitic, medium grained. Sample 1	20.95	45.77	1	6
h Limestone, dark gray to blackish, clayey, thin bedded, weathering to a black soil			4	0
g Limestone, dark gray to blackish, clayey, thin bedded (end of second trench)			16	0
f Limestone, dark gray, clayey, with chert bands 1 to 4 inches thick, shale bands and limestone bands 2 to 8 inches thick			6	0
e Shale, dark clayey, much weathered			2	0
d Phosphate shale				1
c Shale, black, not well exposed			5±	
Wells formation (?):				
b Sandstone, fine grained, calcareous (or siliceous limestone), dark gray, broken into small angular pieces (end of first trench)			2	0
a Limestone, fine grained, greenish gray; weathers much lighter; joint planes well developed				10
Wells formation:				
Sandstone, yellow; base of section.				
			43	0

The phosphate band in which the section was made is probably faulted out both north and south of the canyon, but it is readily accessible by road from the valley to the west. The Survey prospect was made in three trenches, planned to cover a continous stratigraphic interval, which aggregated 191 feet in length and ranged from 1 foot to 5 feet 7 inches in depth. The general strike and dip of the rocks, determined from the Wells formation below and the Rex chert member above, were N. 30° E. and 28° E., respectively.

The section shown in the table is not complete, for it proved impracticable to continue the trenching entirely across the phosphate shales. It does, however, include more than half the distance across the shales. By comparison with the apparent thickness of the shales at McDougals Pass and at places on Swift Creek and the southern Dry Creek, the thickness of the shales here seems somewhat less than normal, and this suggests that part of the section may be faulted out. Some deformation in the shales at the Survey prospect is indicated by the brecciation of some of the beds and the presence of folds in other beds.

The analyses show a lower content of phosphoric acid than might be expected from the general appearance of the rock. Some of the deficiency may be due to the presence of infiltered dirt along bedding and joint planes.

At McDougals Pass the phosphate shales strike N. 11° W. and dip 16° W. The breadth of the outcrop is about 225 feet, but the actual thickness of the shales appears to be about 65 feet. Two phosphate beds are hard enough to form low ledges. The lower bed is about 16 feet above the base and is 2½ to 3 feet thick. A sample from this bed yielded on analysis 22.36 per cent of P_2O_5, equivalent to 48.86 per cent of tricalcium phosphate. A second bed about 24 feet above the base and about 1 foot thick yielded on analysis 31.3 per cent of P_2O_5, equivalent to 68.40 per cent of tricalcium phosphate. As it was impracticable to make a trench in the phosphate shales the number of phosphate beds and the thickness of each could not be accurately determined.

In the southern Dry Canyon the phosphate shales are present in apparently normal thickness. They have been prospected on the north side of the canyon, in the westernmost of the three bands that cross the canyon. The prospect, an old tunnel, has caved and has been so covered by slides that no examination or measurements of the shales could be made. A sample of float from the sag on the hill to the south across the canyon was found by analysis to contain 33.31 per cent of P_2O_5, equivalent to 72.7 per cent of tricalcium phosphate.

Phosphate float is found along the base of the ridge on the upper course of Swift Creek, in T. 32 N., R. 117 W., and it seems probable

that the phosphate band which there lies on the west side of the divide continuing northward becomes the band exposed at McDougals Pass. According to Mr. Jewell, of Afton, the phosphate occurs in the head of Corral Creek east of the divide. It appears to cross the divide at the sag between the heads of the two creeks. A sample taken from a large piece of float near the head of Swift Creek yielded 31.59 per cent of P_2O_5, equivalent to 69 per cent of tricalcium phosphate.

From the samples at McDougals Pass, the southern Dry Creek, and Swift Creek it is evident that high-grade rock is present in the phosphate shales of this portion of the Salt River Range. The occurrence at McDougals Pass suggests that this high-grade bed may not exceed 1 foot in thickness. More prospecting and sampling will be necessary to determine the relative importance of the richer material. From the Willow Creek and McDougals Pass section it is evident that there are two beds near enough together to be worked as one bed aggregating 3 to 3½ feet of phosphate rock and yielding from 45 to 50 per cent of tricalcium phosphate.

METALLIFEROUS PROSPECTS.

A number of metalliferous prospects are reported in some of the canyons east of Fairview, in T. 31 N., R. 118 W. The only one of these visited was Nielson's tunnel, in Dry Canyon, about 1½ miles above the mouth of the canyon. The tunnel is located on a minor fault zone in the Twin Creek limestone, about 200 feet east of a larger fault, between the Twin Creek limestone and the Ankereh formation. The tunnel was too badly caved to permit examination of any but the exterior portions. No mineral was seen in the mouth of the tunnel or on the dump.

THE CANYON SECTIONS.

DRY CREEK (T. 31 N., R. 118 W.)

A traverse was carried up the southern Dry Creek canyon as far as the sawmill, a distance of about 5 miles. The geologic features, as observed and interpreted, are shown graphically on the map (Pl. XII) and the accompanying structure, section A–A′. The supposed fault along the west base of the range (see p. 338) is believed to lie at the mouth of the canyon, where it is concealed by alluvium.

The eastward-dipping ledges (Thaynes or, possibly, Woodside) near the mouth of the canyon are succeeded on the east by characteristic Nugget sandstone, which is exposed in ledges at the national forest boundary. The dip of the fault plane between the two formations appears to be 52° E. The boundary is interpreted as a fault because

of the absence of beds that are elsewhere characteristic of the upper Thaynes and of beds assignable to the Ankareh.

Twin Creek beds, almost vertical but inclining east or west, come next to the Nugget. The boundary here also is interpreted as a fault, because of the absence of the light-colored sandstones and red and green shales elsewhere found in the upper part of the Nugget and because of the absence of the lower heavy limestones and the accompanying green band usually found in the lower part of the Twin Creek. East of the Twin Creek are chocolate-colored to red sandy shales assigned on lithologic grounds to the Ankareh, the boundary being a fault because of the absence of the Nugget sandstone. The two faults bounding the Twin Creek in this part of the section are interpreted as normal. An alternative interpretation would consider them as reverse, but this view is regarded as improbable, for reasons stated below.

The Twin Creek limestone reappears east of the Ankareh shale in fault relation, the Nugget sandstone being absent. About 200 feet east of the main contact is a small subsidiary fault on which is located Nielson's tunnel, a metalliferous prospect. Here the fault clay shows beautiful, nearly horizontal slickensides on a surface dipping steeply to the west. The Twin Creek is succeeded up the canyon by the Nugget, again without the usual lower beds of the Twin Creek and upper beds of the Nugget, and hence this boundary also is interpreted as a fault. The faults east and west of the Twin Creek are considered as normal. If they are reverse, the structure of the Twin Creek would appear to be that of an abnormal synclinorium, a sort of flask-shaped fold, overthrust by Ankareh beds on the west and Nugget beds on the east. Such a structure, though possible, does not seem probable, for most of the other folds do not suggest marked overturning, such as might be expected if this Twin Creek belt and the other Twin Creek belt above mentioned had been abnormally folded and overthrust.

The Nugget sandstone is succeeded eastward by chocolate-colored shaly beds assigned on lithologic grounds to the Ankareh, apparently in normal stratigraphic position. East of the Ankareh shale lie the siliceous limestones of the Thaynes and Woodside formations, without observed stratigraphic break. The Meekoceras zone was not recognized, though it may be present, and the two formations were not differentiated. They form a succession of wall-like ledges with narrow gateways. A zone of red rocks more shaly than the inclosing strata and resembling the beds above referred to the Ankareh shale intervenes in the section. These red rocks are overridden on the west by the Thaynes limestone and Woodside shale. At first it was thought that they were part of the Ankareh, but sections in canyons to the north show red beds that are apparently included in

the Thaynes and Woodside formations. Hence the red beds are tentatively considered Woodside, with a fault on the west side that appears to truncate them. East of the red beds are typical calcareous shales of the Woodside.

The Phosphoria formation succeeds the Woodside on the east. The Rex chert member is here more of a cherty limestone than a chert. It is nodular and shows some quartzitic tendencies. Near the base there is a black band of phosphatic chert 2½ to 3 feet thick. About 20 feet beneath this band there is a highly fossiliferous calcareous zone with Productus, Spiriferina, and other forms. A covered zone about 150 feet wide represents the phosphate-shale horizon, and next appears a poorly developed "under limestone," more or less fragmentary, succeeded by a white, calcareous sandstone, almost a quartzite. Excellent phosphate float was found by ascending to the sag on the hill to the south. The zone between the phosphate shales and the top of the Wells may include a minor fault, as shown by the above-noted condition of the "under limestone" east of the phosphate shale.

The anticlinal structure of the formations in this part of the canyon brings the phosphate shales across the canyon again about three-fourths of a mile farther east and some of the succeeding formations recur in ascending order. The fault between the Woodside and the Wells is interpreted as reverse, because of the crumpled condition of the Wells to the east and its apparent position near the apex of a broken anticline. It seems more likely that such a fault was developed by compression associated with the folding, than under later tension. The fault to the east, within the Wells, is believed to have a steep dip and is interpreted as normal. The general relations produced by it are similar to those of the fault near the east border of the anticlinorium in T. 32 N., R. 118 W., and it seems probable that the two faults are continuous. The fault west of the sawmill is considered as reverse, for it seems to descend obliquely westward into the canyon from the northeast.

SWIFT CREEK.

A traverse was carried up Swift Canyon as far as the crossing of the second Phosphoria band, about 6 miles above the mouth, and a reconnaissance trip carried the investigation of the canyon to the head of the creek, some 7 miles farther. The map (Pl. XII) and the accompanying geologic structure, sections B-B′ and C-C′, show the stratigraphic and structural details along the traversed part of the canyon as recognized and interpreted.

For reasons given on page 338 a fault is supposed to occur along the west base of the range and cross the mouth of the canyon. Tertiary conglomerate and eastward-dipping Twin Creek beds, becoming

vertical toward the east, occupy the lower portion of the canyon. The boundary between the Twin Creek limestone and the Nugget sandstone on the east is regarded as a normal fault because of the absence of beds elsewhere characteristic of the upper part of the Nugget and the lower part of the Twin Creek, and because of the supposed steep inclination of the fault plane. It is tentatively assumed that this fault corresponds with a similar fault in the southern Dry Creek section, and the two faults have been provisionally connected, as indicated on the map.

The Ankareh formation, dipping steeply to the west, lies east of the Nugget in apparently normal thickness. The boundary between these beds and the adjacent Thaynes limestone may perhaps be a fault, because the siliceous beds that form the upper part of the Thaynes in some parts of the field do not seem to be present here. There may, however, be local lithologic changes in the formation. The Ankareh band on Swift Creek is tentatively connected with that on Dry Creek to the south because of similar structural relations.

The Thaynes and Woodside formations to the east have not been differentiated, as the Meekoceras zone was not observed, though some search for it was made. Possibly some fault may occur within this group, as in Dry Canyon, but such a fault was not recognized.

The Rex chert member of the Phosphoria appears in unusually prominent wall-like cliffs that form a narrow gateway at the creek. The phosphate shales are concealed here beneath heavy talus on the steep canyon walls. There appears to be room for them, however, and search in this zone along higher levels in the canyon would doubtless be rewarded by the finding of phosphate float.

East of the Phosphoria the canyon becomes wild and rugged in an anticlinorium of Carboniferous quartzites and limestones. About a mile above the Rex ledges the canyon enters the axis of a syncline trending almost due north. The syncline appears on the east side of the canyon with almost diagrammatic clearness when viewed along the axial line from a point to the north. Near the point where the main creek turns eastward the Wells formation in the syncline persists on the west side of the canyon, because the canyon wall is steeper than the dip of the rocks, but on the east side the Wells appears to have been removed from the gentler slope of the canyon wall, which forms an unusually fine dip slope on the Brazer limestone.

In the main canyon east of the forks successive folds in the Brazer limestone and the Wells formation are clearly exposed on the south side of the canyon. Just east of the axial region of the eastern anticline, which is faulted, a small, steep-sided ravine in nearly vertical rocks of the Wells contains the intermittent spring, locally known as "the geyser," which supplies nearly half the volume of the creek.

About half a mile east of the intermittent spring the eastern Phosphoria band crosses the canyon with a steep easterly dip. The Wells and the Rex again form prominent ledges. The phosphate shales are exposed in the trail with some float of phosphate. This is very likely the place from which C. L. Breger collected his samples in 1910, to which reference is made in Blackwelder's report.[1]

East of this locality the canyon lies in rocks younger than the phosphate shales, rising into the Nugget, which occupies the core of a broad syncline. Farther east the formations appear in descending order with westerly dips. Their boundaries were not determined. The head of Swift Creek lies in a rather broadly opened valley in the Woodside and Thaynes formations. East of this valley is a ledge of Rex chert that forms a hogback along the main ridge west of the divide and is succeeded by phosphate shales to the east. The Phosphoria formation continues southward along the range and appears to go through the sag which forms the divide between Swift Creek and Corral Creek. A pedestrian who was encountered on the trail reported "coal" in the sag. The crest of the ridge north of the sag appears to be formed of pre-Phosphoria rocks.

NARROWS OF SALT RIVER.

A reconnaissance in the vicinity of the narrows of Salt River and in the lower valley of Willow Creek, in the western part of T. 33 N., R. 118 W., shows that this part of the region is underlain by the Nugget sandstone and the Twin Creek limestone. These formations are largely concealed by alluvium and Tertiary conglomerate except where the latter are cut through by the deeper canyons. The structure of the Salt River valley a short distance west of sec. 19, where the river enters the narrows, is synclinal in the Twin Creek limestone, which is well exposed. The east side of the valley forms a fine dip slope for a short distance. A fault between the Twin Creek and Nugget, near the southeast corner of sec. 20 is tentatively regarded as the probable continuation of the fault supposed to lie along the west base of the Salt River range to the south.

PHILLIPS CREEK.

The outer slopes of the hills at the mouth of the Phillips Creek Canyon are occupied by white float of the Twin Creek and by red soil of the Nugget. The alluvial deposits at the mouth of the canyon also show a steep slope or terrace, as in the Swift Creek and Dry Creek canyons to the south, but here the edge of the terrace is not so scarplike. These facts, together with the fault in the foot slopes, near the southeast corner of sec. 20, already noted, suggest that this zone may represent the position of the supposed fault along the

[1] Blackwelder, Eliot, op. cit., pp. 460–461.

west base of the Salt River Range. The terrace may, however, have no relation to this fault. East of this zone the Twin Creek continues for nearly half a mile, interrupted by a narrow zone of red débris about midway between the south quarter corner and the southeast corner of sec. 33. There are also on the slopes scattered bowlders, probably the remnants of the Tertiary conglomerate. Near the southeast corner of sec. 33 characteristic sandstone of the Nugget crosses the canyon. The beds elsewhere found in the upper part of the Nugget and lower part of the Twin Creek are missing here, so that the boundary is interpreted as a fault. On the east the series descends to purplish limestone and red shaly sandstone, with strong easterly dip. Beds elsewhere characteristic of the lower part of the Nugget and the Ankareh were not recognized east of these Nugget beds, but ledges of the Thaynes and Woodside formations occupy the lower parts of the slopes, with Tertiary conglomerate above. The dip of the Thaynes and Woodside beds is steeply eastward. Their west boundary is doubtless a fault. About a quarter of a mile to the east all the older beds are concealed by Tertiary conglomerate, which appears to occupy the outer hills and the lower slopes of the higher hills to the east. In ascending these slopes the first rocks of the older series encountered were limestones lithologically resembling some members of the Thaynes and Woodside formations, but possibly older. The rock is much brecciated and does not show fossils or bedding. Float on the hill above seems to be of Wells age or older. A brecciated ledge lithologically resembling the upper part of the Wells formation comes about 200 feet beyond the supposed Thaynes and Woodside formations, and about the same distance eastward is a clear limestone with large cup corals, Syringopora, and crinoid stems, apparently part of the Brazer limestone. The Phosphoria formation does not seem to be represented in the section. If the above interpretations are correct there is a fault between the Thaynes and Woodside and the Wells and probably one also between the Wells and the Brazer. About half a mile to the east, on the higher slopes, are dark, relatively thin-bedded limestones, containing a few cup corals and crinoid stems and lithologically resembling some portions of the Madison limestone. The dips here are westerly instead of easterly, as in the Brazer beds to the west. The structural relations of the intervening area are obscured by vegetation and were not worked out.

WILLOW CREEK.

At the mouth of Willow Creek a pronounced scarp or terrace 15 or 20 feet high occurs in the gravels, as on a number of creeks to the south. Parts of this terrace are underlain by ledges of Nugget sand-

stone with low easterly dips, and up the hillside 1,000 feet or more to the east are massive ledges of the upper part of the Wells formation. A fault doubtless intervenes between the two formations, but its position is concealed by the surface cover. A little less than half a mile up the canyon the Phosphoria formation is exposed. The Thaynes limestone was not recognized in the section, though it may be present. The Woodside shale is cut off by a fault on the east which brings in the Madison limestone. This fault is tentatively regarded as normal, with downthrow on the west. The Madison limestone dips steeply east and is in turn cut by a supposed normal fault that brings in the Wells formation. Only a part of the Wells with the succeeding Phosphoria formation is present. A fault at the horizon of the Phosphoria cuts out much of that formation. The nature of this fault was not determined, but it is tentatively regarded as normal because of the steep inclination of the formations involved. Structure section D–D′, Plate XII, shows the observed and interpreted structural features of the traversed portion of the Willow Creek section.

The trail from Willow Creek to McDougals Pass lies wholly within post-Phosphoria rocks ranging from the Woodside shale to the Nugget sandstone. A specially fine section from the Nugget down to the phosphate shales is exposed along the Willow Creek trail between a point about a mile below the pass and the pass.

The pass itself is occupied by the phosphate shales, which here cross the divide from the southeast and descend to the head of Strawberry Creek. They also turn back north of the pass on the east side of the divide for at least a short distance. The dip of the rocks at the pass is westerly, while farther west, half a mile or more beyond the point where the trail leaves the main canyon of Willow Creek, there is a smooth dip slope in the eastward-dipping beds of the Woodside shale. Thus it seems that the structure west of the divide is synclinal, whereas an anticlinal axis probably lies at the head of Bear Creek east of the divide. According to Peale,[1] this anticline is sharp and probably is complicated by a fault which he thinks may be continued down the head of Glacier (now called Strawberry) Creek.

DRY CREEK (T. 33 N., R. 118 W.).

At the mouth of the Northern Dry Canyon heavy limestones of the Wells formation occur in an anticline that is steep sided, slightly inclined eastward, and faulted on the east limb. The Madison limestone, which lies east of the fault, is also steeply folded in an anticline. This rock in turn appears to be cut by a fault on the east, which brings in a narrow strip of the Brazer limestone, followed on

[1] Peale, A. C., U. S. Geol. and Geog. Survey Terr. Rept. for 1877, pp. 546–547, 1879.

the east by the Wells formation, both with steep easterly dips. The Wells is faulted on the east against the Woodside shale, which here consists of about 200 feet of deep-red and gray shales with shaly sandstone. The Woodside beds have a synclinal structure, the axis running about along the line of the gulch to the north. Phosphate float was found along the west side of this gulch about half a mile north of its mouth. Float pieces of the Meekoceras-bearing rock occur nearly half a mile east of the northeast corner of unsurveyed sec. 6, T. 33 N., R. 117 W. The general structural features of the Dry Creek section as above interpreted are shown in structure section E–E′, Plate XII. Post-Phosphoria rocks appear to continue from the Meekoceras zone up to McDougals Pass. The above-mentioned fault between the Wells and the Woodside is tentatively considered the northward continuation of the similarly located fault in Willow Creek Canyon near the east boundary of T. 33 N., R. 118 W. In each locality post-Phosphoria rocks lie to the east and prephosphate rocks to the west of the fault, while the structure east of the fault appears to be synclinal.

STRAWBERRY CREEK.

No traverse was made in Strawberry Canyon, but a reconnaissance trip was made from McDougals Pass down this canyon to Bedford.

The position of the fault thought by Peale to occur at the head of Strawberry Creek was not determined. The headwater region of the creek is a broadly opened trough that appears to lie in a syncline pitching gently to the south. Dip slopes occur on both sides of the creek, but the formations involved were not examined at close range. The phosphate shales continue down the west side of the canyon for 1½ or 2 miles to a point where they cross the creek and ascend the east side of the valley. They form a noticeable black soil in the creek bank and on the adjacent slopes at the point of crossing. Below the point of crossing the rocks in Strawberry Creek are all older than the Phosphoria, and the canyon becomes rougher and more timbered. The course of the creek to the bend, where the creek turns west, appears to continue in the syncline, with the Wells formation at the core. The structure of the axial region where exposed in the hills north of the bend in the creek is complex, and there is some evidence of overturning toward the east. West of the bend the rocks range in age from Wells to Madison and the structure is apparently broadly anticlinorial. Peale[1] recognized two anticlines and an intervening syncline in this part of the canyon. The western anticline, he stated, is sharper than that to the east, and the western members of it pass under the valley of Salt River.

[1] Peale, A. C., op. cit., pp. 546–548.

The Phosphoria formation does not extend as far north as Strawberry Creek west of the great bend. It may turn back along the anticline or perhaps be faulted out. The geology north of Strawberry Creek is not well known, but it seems probable that the rocks will prove to be pre-Phosphoria. Peale reports that nothing younger than Carboniferous appears north of the creek, at least as far north as his station 57 (8 miles north).

On the occasion of Peale's visit to this region, in July, 1877, the head of Strawberry Creek was filled with a huge snow bank, reminding him of a glacier, which extended for several miles down the gorge. On its surface were rocks and earth, and at the bottom a mass of detrital matter resembling a small terminal moraine. Doubtless this occurrence suggested the name Glacier Creek used in his report, though this name is not now in use. He expressed doubts as to the glacial character of the snow bank. On the occasion of the writer's visit, October 1, 1914, there was no snow in the canyon, although a snowstorm occurred two days later. The accumulation of débris noted by Peale was observed. This and the troughlike character of the upper valley from a point perhaps a mile below the great bend indicate the probability of glaciation within comparatively recent geologic time, if not actually at the time of Peale's visit.

West of the mouth of Strawberry Canyon limestones of probable Madison age crop out in a few low knolls along the base of the range. The westernmost exposure of these rocks observed was in the northeast corner of sec. 28, T. 34 N., R. 118 W. Other outlying knolls and part of the lower foot slopes of the range are covered by Tertiary conglomerates. The bottom lands are covered with alluvial deposits, which, from indications in T. 33 N., R. 118 W., may be underlain in part by Nugget or Twin Creek beds. Between these and the older Carboniferous rocks to the east there is probably a concealed fault. The position of the supposed fault is not known, but if present the fault must lie west of the northwest corner of sec. 28, T. 34 N., R. 118 W.

CASSITERITE IN SAN DIEGO COUNTY, CALIFORNIA.

By Waldemar T. Schaller.

A small handful of cassiterite crystals was found in the northern part of San Diego County, Cal. (fig. 22), in the spring of 1915, and the locality was visited by the writer in July, in order to see if it offered any hope of finding cassiterite in quantity. Mr. Roy Carson was kind enough to act as guide, and the writer wishes to thank him for his many courtesies. The locality lies in an arid region, best reached

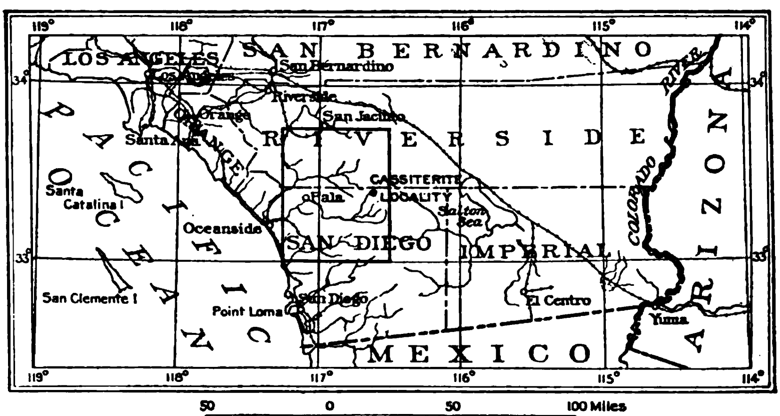

FIGURE 22.—Index map showing position of cassiterite locality in San Diego County, Cal. The rectangle indicates the gem tourmaline field of southern California, throughout which are found pegmatite dikes similar to the one described in this paper.

by horseback from Oak Grove, although a wagon road, now in bad condition, leads from Oak Grove to a point within a mile of it. The present owners of the claims (Messrs. Roy Carson, E. L. Haney, and D. H. A. Fiske, of Pasadena), expect to do further development work in 1916.

The original material, extracted from a single pocket in a flat-lying pegmatite dike,[1] is all the cassiterite so far obtained, and an examination of the locality has failed to offer any hope of finding more in large quantities. The deposit illustrates well the irregular way in which the rarer minerals occur in the granitic pegmatites of southern California.

[1] The term dike as used in this paper carries no implication as to dip, which may be more nearly horizontal than vertical.

Although the present developments have been disappointing, the cassiterite found exceeds in quantity all the occurrences of tin ore in place previously known in San Diego County. These are as follows: F. J. H. Merrill[1] has stated that small grains of cassiterite have been obtained by placer miners from the black sand of the mountain gulches, chiefly from the east slope of Laguna Mountain, in the southern part of the county. Additional reported occurrences are in Pine Valley; on the south end of Viejas Mountain, east of Alpine; and in the Defiance copper district, north of the Santa Margarita grant. The writer[2] has described small black crystals of cassiterite, a few millimeters thick, associated with albite, quartz, stibiotantalite, and green and pink tourmalines, obtained from the gem pegmatite dike at the Himalaya mine, Mesa Grande, and with topaz from the Little Three gem mine, Ramona. The original San Diego County included the tin mines at Temescal, now in Riverside County.

The pegmatite dike which yielded the cassiterite crops out on the east side of Chihuahua Valley, about 2 miles south of the boundary line between Riverside and San Diego counties and about 10 miles east of Oak Grove, in the SW. ¼ sec. 12, R. 3 E., T. 9 S., San Bernardino meridian. Three claims, the San Diego, Panama, and Exposition, cover the outcrop of the dike. There are at least two other parallel dikes on the claims which have not yet been developed. The place was discovered and located in 1905 by Mr. Bert Simmons, of Oak Grove. The claim, then called the Blue Tourmaline, was worked extensively in 1906, by open cuts and several short tunnels, the main object of search being gem tourmaline.

The country rock of the region is granitic and belongs to the group intermediate between granite and diorite. The specimens collected contain quartz, orthoclase, plagioclase, biotite, and hornblende, and pending further study may be termed granodiorite. Many of the hornblende and biotite crystals are from 0.5 to 1 centimeter across.

A system of parallel faults, of which the major ones are over 50 miles in length, cut across the country in a northwesterly direction (about N. 40°–50° W.), and the locality described lies about halfway between two of these larger faults. It is probable that other as yet undetermined dislocations lie between the two mentioned. A northwest fault line probably determines the east side of Chihuahua Valley, and the dike containing the cassiterite occurs less than a mile east of this supposed fault line. Numerous pegmatite dikes, striking parallel to the fault lines, crop out on the east side of Chihuahua Valley.

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[1] Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial Counties: California State Mineralogist's Rept., 1913-14, p. 39, 1914.

[2] Schaller, W. T., The gem tourmaline field of southern California: U. S. Geol. Survey Prof. Paper 92 (in preparation).

The western fault of the two mentioned determines the east side of Smiths Mountain, and extends from a point north of Aguanga, in Riverside County, southeastward through Oak Grove, Puerta Cruz, and Warners Hot Springs (Agua Caliente), probably forming the east side of the valley occupied by Warner's ranch. The eastern fault line, whose exact location is not known, passes through San Jacinto and Hemet, skirting the west and southwest edge of the San Jacinto Mountains, and through the Coahuila Valley and Coyote Canyon.

The remarkable parallelism of strike of nearly all the pegmatite dikes of this region with the larger fault lines is very suggestive of a possible genetic relation. Similar pegmatite dikes occur at Pala, and a detailed study of this locality has indicated that the fissures now filled with pegmatite are part of a large system of dislocations prominently developed in San Diego County.

The exposed length of the pegmatite dike in which the cassiterite was found is nearly half a mile, and the thickness from 6 to 8 feet. The pegmatite rock is more resistant to erosion than the granodiorite country rock, and the dike therefore projects slightly above the ground. It strikes about N. 35° W. At the north end of the claims the natural exposure of the dike seems to show it dipping slightly toward the northeast; at other places it lies almost horizontal, and at still other places a slight but decided dip toward the southwest is observable.

The pegmatite dike is of the type of the compound, unsymmetrical dikes whose different parts are thought to be due to differentiation processes rather than to multiple injections of material into reopened fissures.

The upper portion of the dike ("top rock"), from 2 to 3 feet thick, is a mixture of a coarse granular aggregate of quartz and feldspar with coarse graphic granite, in both of which occur biotite, muscovite, and black tourmaline. At one place a horizontal layer of graphic granite 4 inches thick was seen in the granular aggregate.

The lower portion of the dike ("bottom rock"), about 3 feet thick, is a finer-grained granular quartz-albite rock with numerous wavy bands of garnets, which in their general trend lie horizontal, being parallel to the dip of the dike.

The middle part, between the top rock and bottom rock, is called the pay streak by the miners, for it is in this part that the minerals of value are found. The pay streak ranges from 1 foot to 3 feet in thickness and is the coarsest part of the entire dike. In it occur numerous cavities or pockets which yield an abundance of large and well-crystallized minerals—quartz, feldspars, and micas—as well as other minerals found only in this part of the dike, such as lepidolite, transparent blue tourmalines, cassiterite, and columbite. The

pocket from which the cassiterite was obtained lies just above the banded bottom rock and is about a foot high and 3 feet wide. The irregular masses and imperfect crystals of cassiterite were found in one side of the pocket in a mass of partly broken, cleaved, and loose orthoclase, directly associated with albite. The loose crystals of cassiterite contain partly embedded tabular albite crystals. About a hatful of small blue tourmalines was also obtained from this pocket. In a similar pocket, about 25 feet distant, a few crystals of columbite were found.

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